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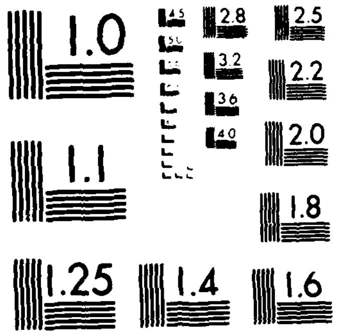

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Report No. CG-D-34-84

SIDE BY SIDE
BUOY TENDER EVALUATION
SEAKEEPING AND MANEUVERING COMPARISONS
OF THE USCGC MALLOW (WLB-396)
AND SSP KAIMALINO
(SEMI-SUBMERSIBLE PLATFORM)

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FINAL REPORT

FEBRUARY 1984

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16. Abstract

The SSP KAIMALINO, an 89 foot, 225 long ton Small Waterplane Area Twin Hull (SWATH) ship, is evaluated as a buoy tender platform, side by side with the USCGC MALLOW, a 180 foot, 1,025 long ton monohull buoy tender. Seakeeping comparisons are presented during runs underway in 10.4 and 4.3 foot significant wave heights at 8 and 12 knots respectively. The SWATH proved to have far superior seakeeping abilities compared to the conventional displacement hull buoy tender in the seaway.

Buoy tending evaluations were simultaneously conducted in 4.3 foot significant wave heights. Vessel motions in roll and pitch are compared during slow speed (0-2 knots) buoy tending operations.

A comparison of vessel maneuverability was accomplished by conducting Dieudonne spiral maneuvers as well as zig-zag (overshoot) tests at both 4 and 8 knot runs. Both vessels demonstrated good maneuvering control.

These tests were a joint effort with the U.S. Navy. Navigation, leeway, station keeping and buoy tending evolutions were evaluated and presented in a separate companion report entitled, "Side-By-Side Buoy Tending Trials of the SWATH Ship SSP KAIMALINO and the USCG Cutter MALLOW (WLB-396)" by A.T. Strickland, published by the Naval Ocean Systems Center, San Diego, CA.

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METRIC CONVERSION FACTORS

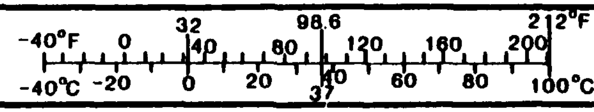
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The Naval Ocean Systems Center, Hawaii Laboratory and U.S. Coast Guard Research and Development Center were jointly tasked by the U.S. Coast Guard Office of Research and Development, to conduct a side by side buoy tender evaluation. This effort is part of an on-going performance assessment of vessels funded under the Advanced Marine Vehicles project. The Coast Guard plans to begin to replace the WLB ocean-going buoy tender class of vessels in the 1990's. These trials have developed a data base which defines the baseline performance of the 180 foot WLB class, as well as assessing the Small Waterplane Area Twin Hull (SWATH) ship concept as one alternative to the present monohull design.

DESCRIPTION OF VESSELS

The SSP KAIMALINO (Semi-Submersible Platform) is an 89 foot SWATH. The design consists of two fully submerged torpedo like buoyancy pods which support a bridging box like superstructure above the water. Four thin struts pierce the water surface between the pods and support the platform above. This concept reduces ship motions by limiting the waterplane area which is subject to passing waves. The KAIMALINO, is a 225 long ton, 1/5 "model" vessel of a proposed full scale SWATH. The seakeeping performance outlined in this report would be improved with a larger (full scale) displacement SWATH.

The USCGC MALLOW (WLB-396) is a 180 foot buoy tender. It is a 1025 long ton single screw monohull vessel designed for ocean-going buoy tending operations. The particulars of both vessels are listed in Table I.

TESTING

The objective of the side by side trials of the SSP KAIMALINO (SWATH) and the CGC MALLOW (WLB) was to obtain comparable data on a SWATH ship performing Aids to Navigation (ATON) tasks relative to a WLB under identical environmental conditions. Seven groups of tests were conducted on 7-11 March 1983 off the island of Oahu, Hawaii, to evaluate selected aspects relating to the effective performance of buoy tending operations. These included seakeeping at transit speeds (8 and 12 knots), seakeeping while setting buoys, maneuvering, navigation by horizontal sextant angles, station keeping, leeway and tending buoys.

The results of seakeeping trials while transiting and tending buoys, as well as maneuvering tests, are presented in this report. The detailed results of navigation, station keeping, leeway and buoy tending portions of the tests are presented in a companion report entitled "Side-By-Side Buoy Tending Trials, SWATH Ship SSP KAIMALINO and The USCG CUTTER MALLOW" published by the Naval Ocean Systems Center, San Diego, California.

The objective of seakeeping trials, side by side, was to measure and quantify the motions of both vessels while transiting to and from operational areas. Better seakeeping abilities translates to faster transit times and less fatigued crew members when arriving on scene to work buoys. Seakeeping trials, while conducting buoy operations at low speeds (0-2 knots), demonstrates the feasibility of working buoys in rough seas at

TABLE I

SSP AND WLB PARTICULARS

	CGC MALLOW	SSP KAIMALINO
Length Overall	180 ft	88 ft 4 in.
Beam	37 ft	46 ft 6 in.
Draft	12 ft 6 in	15 ft 3 in
Design Load Displacement	1025 long tons	225 long tons
Maximum Speed	12 kts	24 kts
Cruise Speed	11.8 kts	13 kts
Endurance	7500 nm	400 nm
Horsepower	1200	4500
Machinery	Diesel-Electric 2 main engines Single screw	Gas Turbine 2 main engines Twin screw
Ride Control	None	Forward Canard Flaps and Stern Strut Flaps
Crew	57	7

various orientations of the vessel to the major swell direction. A more stable platform allows buoys to be worked safely in higher sea states. Buoy tending operations require good vessel maneuverability in both restricted and open waters. Spiral and zig-zag maneuvers were conducted at 4 and 8 knots in order to compare SWATH and WLB course keeping stability, turning and rudder response characteristics.

SEAKEEPING

Two side by side transiting seakeeping evaluations were conducted with the KAIMALINO and the MALLOW. The tests were conducted in the open ocean six miles northeast of Kaneohe Bay off the island of Oahu, Hawaii. Both vessels steamed at constant speed in five directions relative to the major swell: head, bow quarter, beam, aft quarter and stern seas. On 7 March tests were conducted in 6-12 foot swells at 8 knots, while on 10 March the tests were run at 12 knots in 3-5 foot swells. Motion data was measured by two identical ship motion packages installed and monitored by USCG Research and Development Center personnel. Seakeeping data collection during simultaneous buoy tending operations was conducted on 9 March in 5-8 foot swells. During the 12 knot seakeeping runs the KAIMALINO had its ride control system activated, while at 8 knots it was secured because at slow speeds it is not effective. These side by side seakeeping tests compare the MALLOW with the KAIMALINO at its best seakeeping performance level, with the ride control system activated when it improves ride quality.

Instrumentation

The sensors (Humphrey, Inc. motion packages) measured roll, pitch and yaw angles; roll, pitch and yaw rates as well as surge, sway and heave accelerations. The motion package sensor was located on the centerline of the KAIMALINO against the aft bulkhead of the bridge space, as seen in Figure 1. It could not be placed at the vessel's center of gravity which is located outside the vessel's structure below the above water platform. On the MALLOW the sensor package was at the center of gravity located on the centerline in the crew's berthing space 4 feet off the deck, 5 feet forward of the aft bulkhead, Figure 2. Ship motion data was collected continuously by two identical 14-channel Racal analog tape recorders during 20-30 minute transit runs and during 8-10 minute buoy tending runs. Wave heights were measured by a Waverider buoy, supplied by the Naval Ocean Systems Center (NOSC), which was deployed at the center of the transit motion run pattern, and next to the buoy operations area. This arrangement permitted wave data to be collected within 3-4 miles of the steaming operations and within 1/4 mile during buoy tending runs.

Data Reduction

Roll and pitch angle measurements were averaged by computer (Hewlett Packard-9835) over a 20 minute period for each run. Output was in the form of average one-tenth highest (H 1/10) and average one-third highest (H 1/3) roll and pitch amplitude motions. Amplitude was measured from the ships' average heel and average trim during each run.

Heave accelerations were measured for the KAIMALINO on all runs (MALLOW heave data was not collected due to accelerometer failure). Surge accelerations were analyzed for both vessels on head and stern sea runs only.

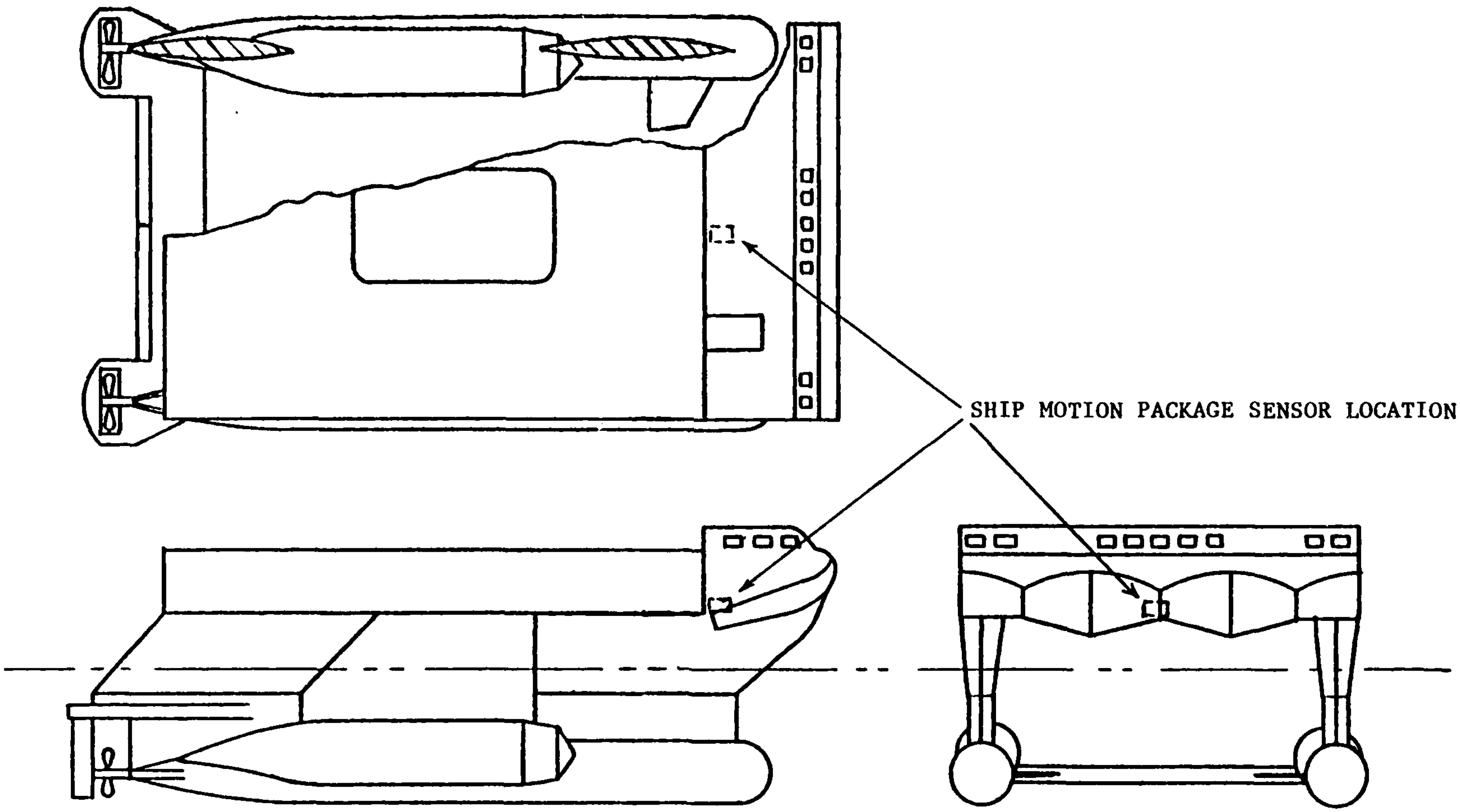


FIGURE 1. SSP KAIMALINO Plan and Profile

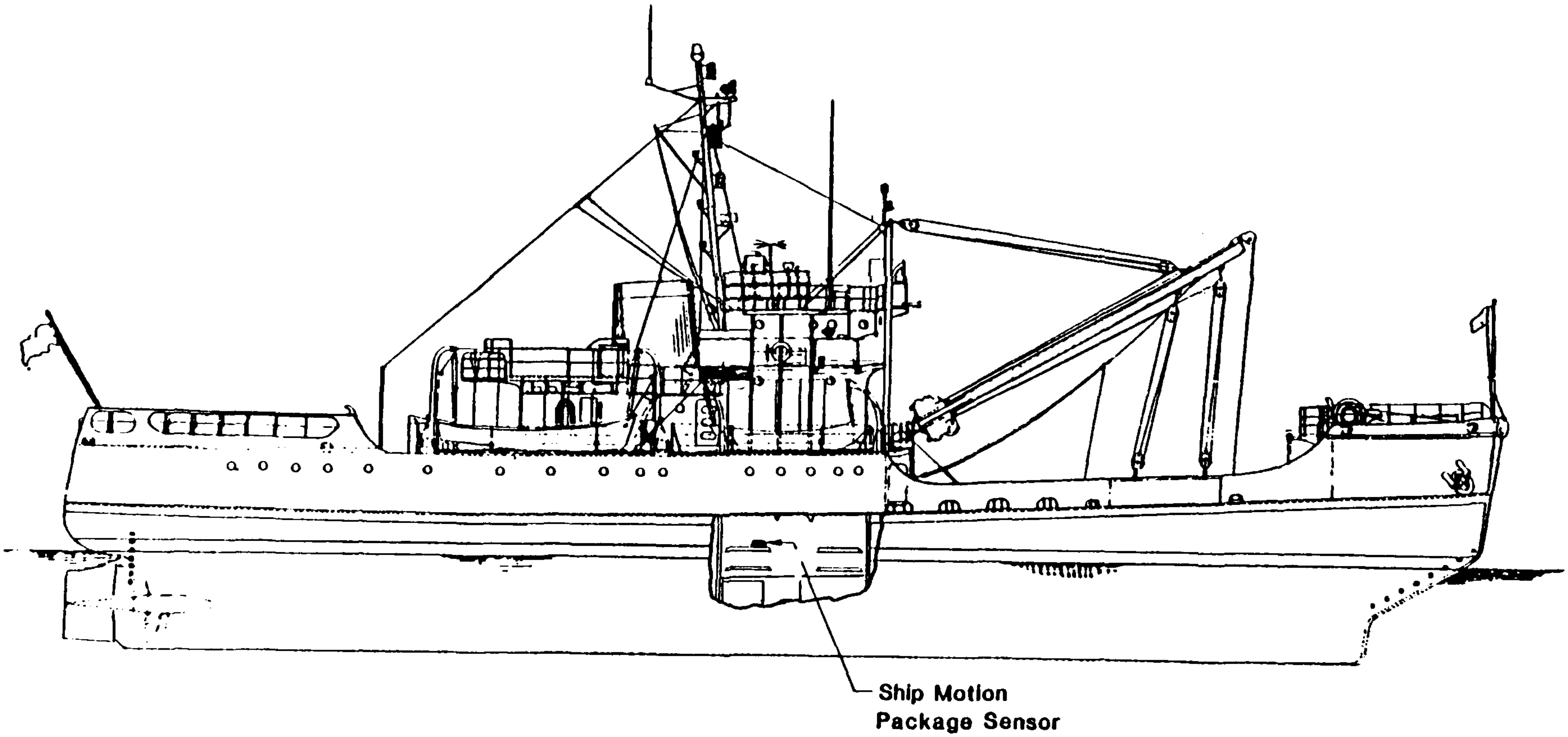


FIGURE 2. USCGC MALLOW PROFILE

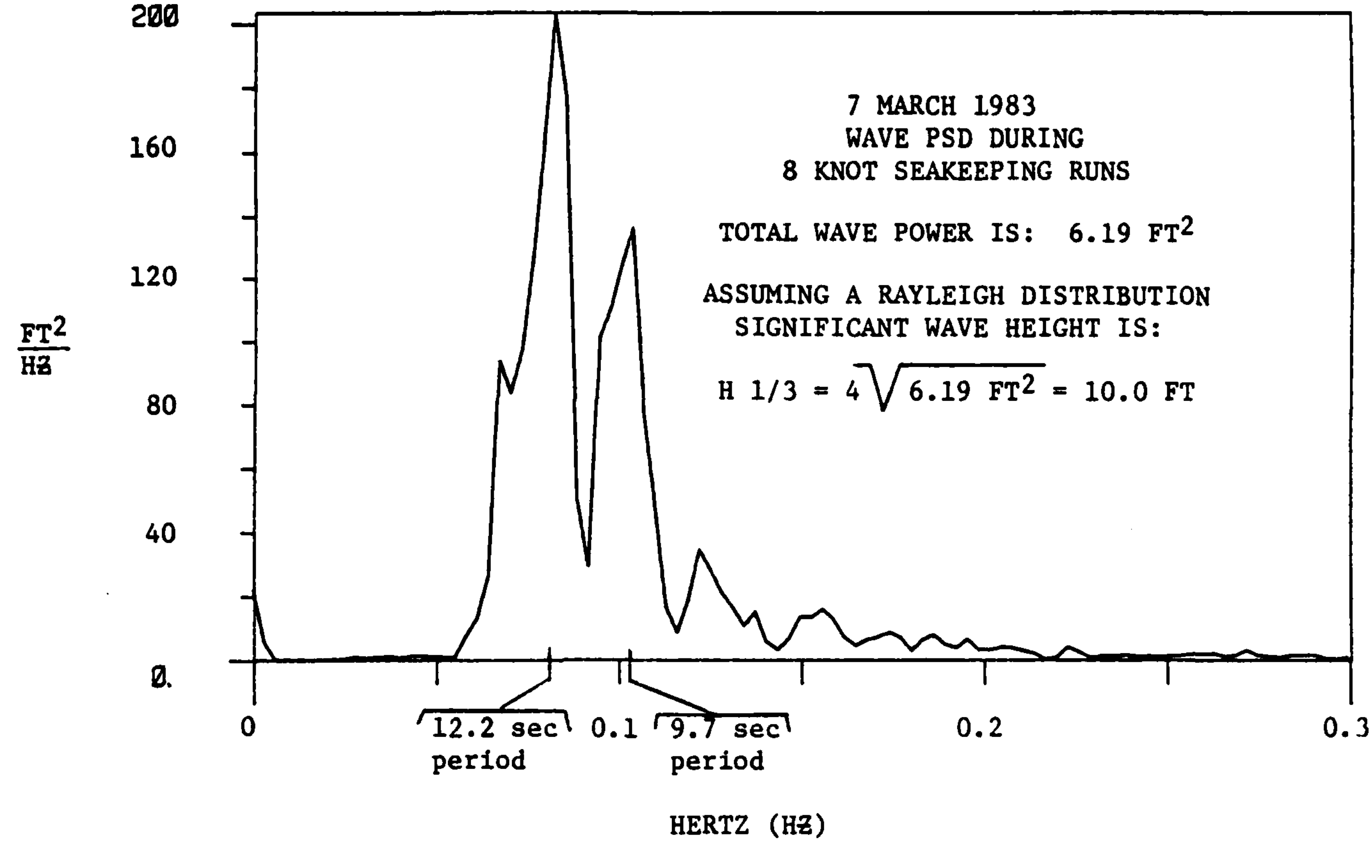
Acceleration output is presented in gravitational acceleration units (G's) single amplitude by computer averaging the highest H 1/10 and H 1/3 accelerations over a 20-minute period on each run.

Wave data was analyzed in two ways. Significant wave height H 1/3, (average of the one third highest waves peak to peak,) was determined by computer averaging wave heights. This was accomplished by analyzing several selected time slots totaling 30 minutes throughout the entire time of the motion runs, approximately a 2-1/2 hour period. In addition to computer averaging the record, a power spectral density (PSD) of the wave height information was generated for each test day utilizing a Hewlett Packard spectrum analyzer (HP-5420A). This was done to quantify the sea spectrum and identify the periods of waves present. Significant wave height data can be estimated from this spectrum by assuming a Rayleigh distribution of waves and computing H 1/3 using the equation: $H\ (1/3) = 4\ (\text{Wave Power})^{1/2}$. This was done; however, the distribution of waves were not always typical of a Rayleigh distribution and the results were sometimes different from the computer averaging of wave heights. There were no local generated wind-driven waves present. All energy was from 9.7 to 12.2 second period smooth unidirectional swells on 7 March with a significant wave height of 10.0 feet, Figure 3. This compares closely with a computer averaged H 1/3 of 10.9 feet. On 10 March tests were conducted in 9.3 to 11.0 second swells with H 1/3 of 3.5 feet. The H 1/3 computer average of 5.0 feet differs from the 3.5 foot value obtained from the wave spectrum in Figure 3. The difference may be attributed to assuming a Rayleigh distribution when computing H 1/3 values from the wave PSD and comparing that continuous 20 minute wave height spectrum measurement with a computer averaged measurement taken at different portions of the wave record for that test period. Significant wave heights presented in this report are an average of both processing techniques, the spectrum H 1/3 output plus the computer average H 1/3 output divided by 2. The results are a H 1/3 of 10.4 feet on 7 March and a H 1/3 of 4.3 feet during 10 March seakeeping trials.

According to NOSC ship test personnel, the sea conditions during this series of tests were not the most ideal case for side by side tests with a Small Waterplane Area Twin Hull (SWATH) ship and conventional monohull vessel. If anything, it tends to favor the conventional displacement vessel. This SWATH responds to some extent to large swells, the situation during these tests; however, it apparently doesn't even "feel" 3 to 5 second period localized wind-driven waves. Conversely, a conventional displacement craft such as the MALLOW will react to these locally generated short crested waves. Despite the sea swell condition which perhaps favored the MALLOW, the KAIMALINO clearly outperformed the MALLOW buoy tender in seakeeping abilities. This is significant considering the KAIMALINO is one-half the length and 4.5 times lighter in displacement than the MALLOW. A further reduction in motions or increase in seakeeping abilities could be expected of a SWATH vessel scaled to the present displacement of the MALLOW with an increase in SWATH length, beam, and displacement from that of the KAIMALINO.

Transiting Seakeeping Results

The SSP KAIMALINO is a much more stable platform than the CGC MALLOW. This was evident by observations as well as through comparative seakeeping results. Two side by side seakeeping tests were conducted in different sea



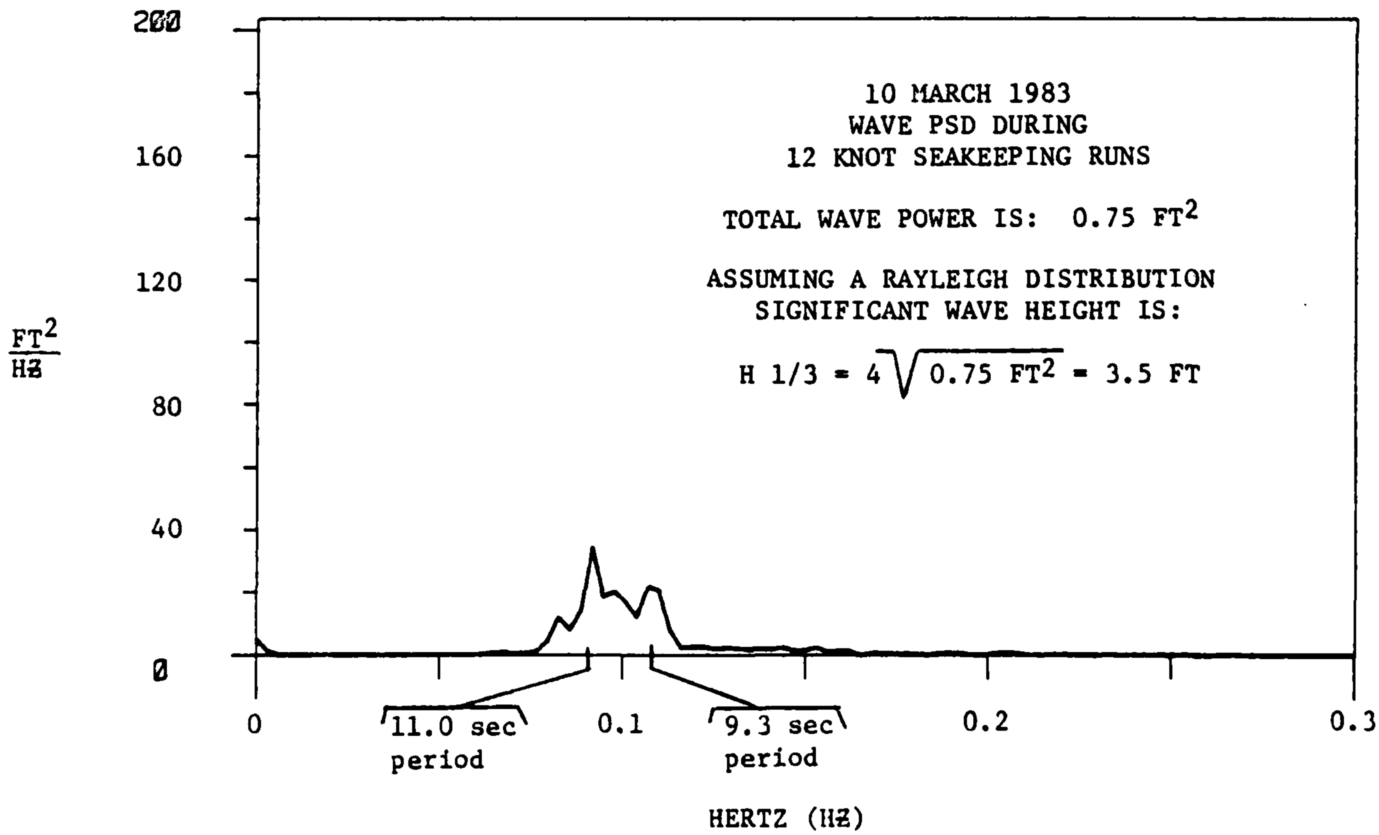


FIGURE 3. WAVE SPECTRUM DURING SEAKEEPING TRIALS

states and speeds. On 7 March in significant swells H 1/3 of 10.4 feet, tests were conducted at 8 knots, Table II. On 10 March significant swells were smaller, 4.3 feet, when tests were conducted at 12 knots as reported in Table III. In beam seas the roll magnitude of the MALLOW was 16 times that of the KAIMALINO when averaged over both test days. The KAIMALINO's H 1/10 rolls never exceeded 1.1 degrees amplitude while the MALLOW's rolls exceeded 20 degrees in 10 foot beam seas, Table II. Roll period for both vessels in beam seas were about the same both days, fluctuating between 7-9 seconds. Pitch angle differences between the two vessels are not nearly as large as those in roll. In head seas the pitch magnitude of the MALLOW (WLB) was 3.8 times that of the KAIMALINO (SSP). In stern seas the WLB outperformed the SSP by pitching 15% less. The wing stabilizers (canards) located on the inside front section of the SSP's submerged buoyancy pods, Figure 1, are not as effective in reducing pitching action and vertical accelerations in stern seas as they are in head seas.

Vertical accelerations cannot be compared due to accelerometer failure on the WLB. The magnitude of heave accelerations measured on the SSP, however, is extremely low. In significant seas of 10.4 feet proceeding at 8 knots with the ride control system off, H 1/3 vertical accelerations never exceeded 0.046 G's single amplitude. Unlike conventional displacement vessels the SSP does not heave more in head seas, as seen in Tables II and III. It has about the same heave response to swells coming from any direction with slightly higher values with stern seas.

Surge accelerations measured on the 1,025 long ton MALLOW were 48% less than those measured on the 225 long ton KAIMALINO in head seas. The overall magnitude of the accelerations, however, was not significant. On the MALLOW they never exceeded 0.024 G's amplitude while the maximum on the KAIMALINO were 0.031 G's amplitude comparing Tables II and III.

The comparative roll and pitch data is more clearly seen when presented on a polar plot. The effects of vessel orientation to the major swell direction are graphically presented. The left side of the vertical axis is data collected from the KAIMALINO while the right side represents the MALLOW.

Figures 4 and 5 dramatically show WLB's roll amplitudes far exceeding those of the SSP in both seakeeping trials conducted on 7 March in significant wave heights of 10.4 feet at 8 knots steaming, and on 10 March in 4.3 foot seas steaming at 12 knots. The SSP is not responsive to beam seas while the WLB rolled extensively (H 1/10 of 7-21 degrees) with beam and quartering seas. The WLB rolled more with bow quartering seas than beam seas while proceeding at 12 knots in 4 foot seas, Figure 5.

Pitch amplitudes of the WLB were greater than those of the SSP in head seas. A higher sea state H 1/3, 10.4 feet, demonstrated larger differences of pitch motions between the two vessels as seen in Figure 6. With a less severe sea state, 4.3 feet, the pitch angle amplitudes for the two vessels were closer in magnitude as seen in Figure 7. The SSP pitch amplitude motions did not respond much differently in the two different sea states while the WLB pitched more in larger seas. In stern seas, maximum pitch amplitude was about the same for the SSP both seakeeping test days, 0.6 degrees.

TABLE II
7 MARCH 1983
SIDE BY SIDE SEAKEEPING
ONE TENTH AND ONE THIRD HIGHEST MOTIONS

SPEED 8 KTS
SIGNIFICANT WAVE HEIGHT (H 1/3) 10.4 ft.

USCGC MALLOW (WLB-396)

RUN #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	*Heave Accel (G's) Amplitude H 1/10	*Heave Accel (G's) Amplitude H 1/3	Surge Accel (G's) Amplitude H 1/10	Surge Accel (G's) Amplitude H 1/3
66-1	Head	5.85	2.80	2.45	1.71			0.024	0.014
	Bow Qtr	(Data Not Collected Due to Time Constraints)						--	--
66-2	Beam	21.22	15.39	0.96	0.65			--	--
66-3	Aft Qtr	13.78	8.44	0.73	0.53			--	--
66-4	Stern	3.75	2.15	0.54	0.43			0.024	0.009

*Heave acceleration data not available due to accelerometer failure

SSP KAIMALINO

RUN #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	Heave Accel (G's) Amplitude H 1/10	Heave Accel (G's) Amplitude H 1/3	Surge Accel (G's) Amplitude H 1/10	Surge Accel (G's) Amplitude H 1/3
66-1	Head	0.43	0.37	0.44	0.39	0.037	0.033	0.031	0.029
66-1B**	Bow Qtr	0.74	0.50	0.53	0.40	0.039	0.034	--	--
66-2	Beam	1.07	0.67	0.44	0.36	0.034	0.031	--	--
66-3	Aft Qtr	1.00	0.65	0.39	0.33	0.064	0.041	--	--
66-4	Stern	0.50	0.42	0.57	0.42	0.078	0.046	0.031	0.030

** Data Collected During Helicopter operations steaming

TABLE III
10 MARCH 1983
SIDE BY SIDE SEAKEEPING
ONE TENTH AND ONE THIRD HIGHEST MOTIONS

SPEED 12 KTS
SIGNIFICANT WAVE HEIGHT (H 1/3) 4.3 ft.

USCGC MALLOW (WLB-396)

RUN #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	*Heave Accel (G's) Amplitude H 1/10	*Heave Accel (G's) Amplitude H 1/3	Surge Accel (G's) Amplitude H 1/10	Surge Accel (G's) Amplitude H 1/3
69-1	Head	3.40	2.14	0.88	0.62			0.011	0.009
69-2	Bow Qtr	9.23	5.99	0.74	0.56			--	--
69-3	Beam	7.70	4.27	0.53	0.43			--	--
69-5	Aft Qtr	3.43	1.90	0.64	0.45			--	--
69-4	Stern	1.60	1.14	0.44	0.38			0.015	0.013

*Heave acceleration data not available due to accelerometer failure

SSP KAIMALINO

RUN #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	Heave Accel (G's) Amplitude H 1/10	Heave Accel (G's) Amplitude H 1/3	Surge Accel (G's) Amplitude H 1/10	Surge Accel (G's) Amplitude H 1/3
69-1	Head	0.44	0.38	0.43	0.35	0.039	0.035	0.025	0.020
69-2	Bow Qtr	0.48	0.38	0.56	0.47	0.041	0.036	--	--
69-3	Beam	0.62	0.47	0.35	0.34	0.040	0.034	--	--
69-5	Aft Qtr	0.72	0.52	0.40	0.35	0.035	0.031	--	--
69-4	Stern	0.46	0.38	0.62	0.55	0.041	0.033	0.020	0.018

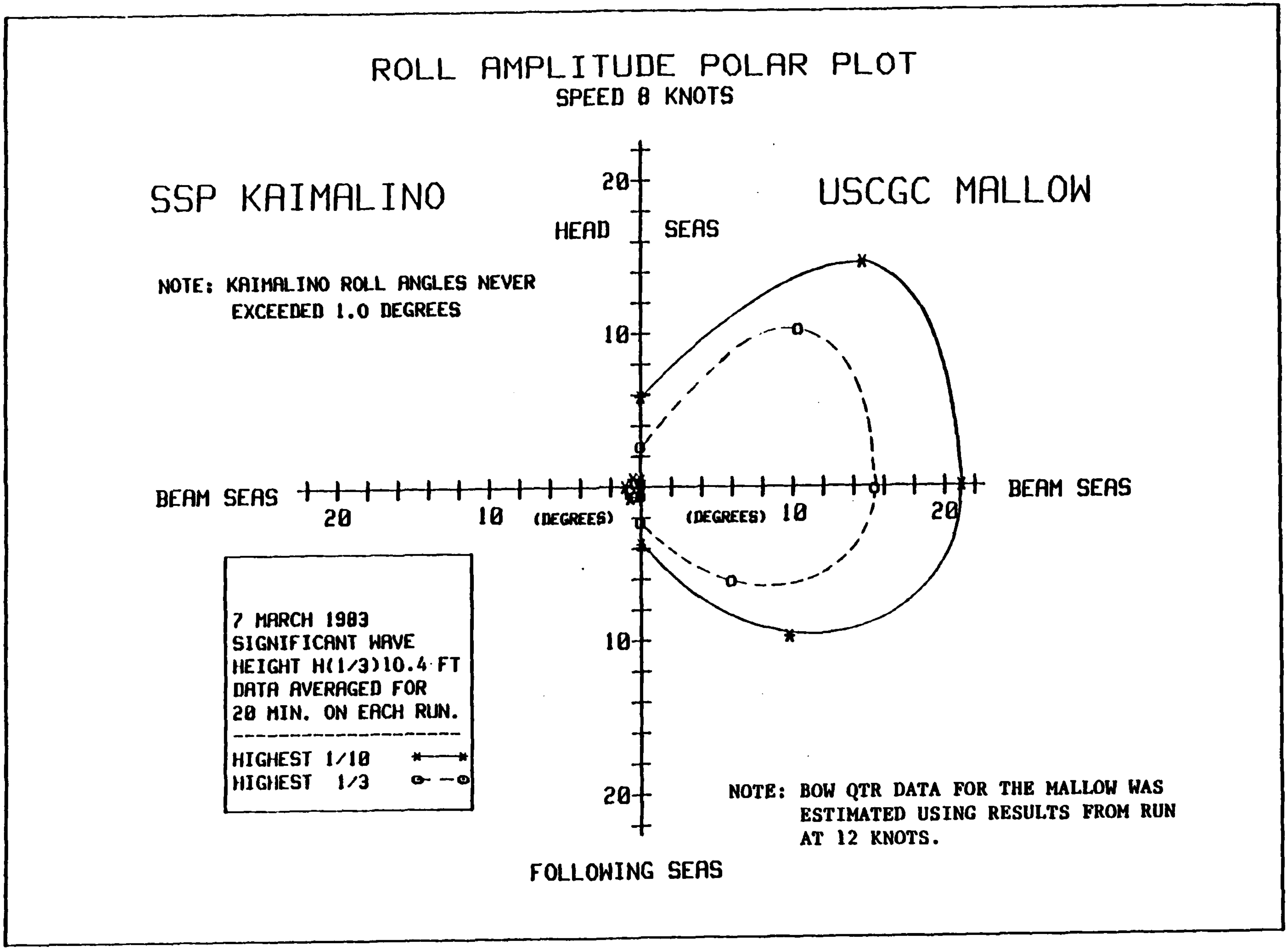


FIGURE 4. Roll Amplitude Polar Plot, 8 Knots

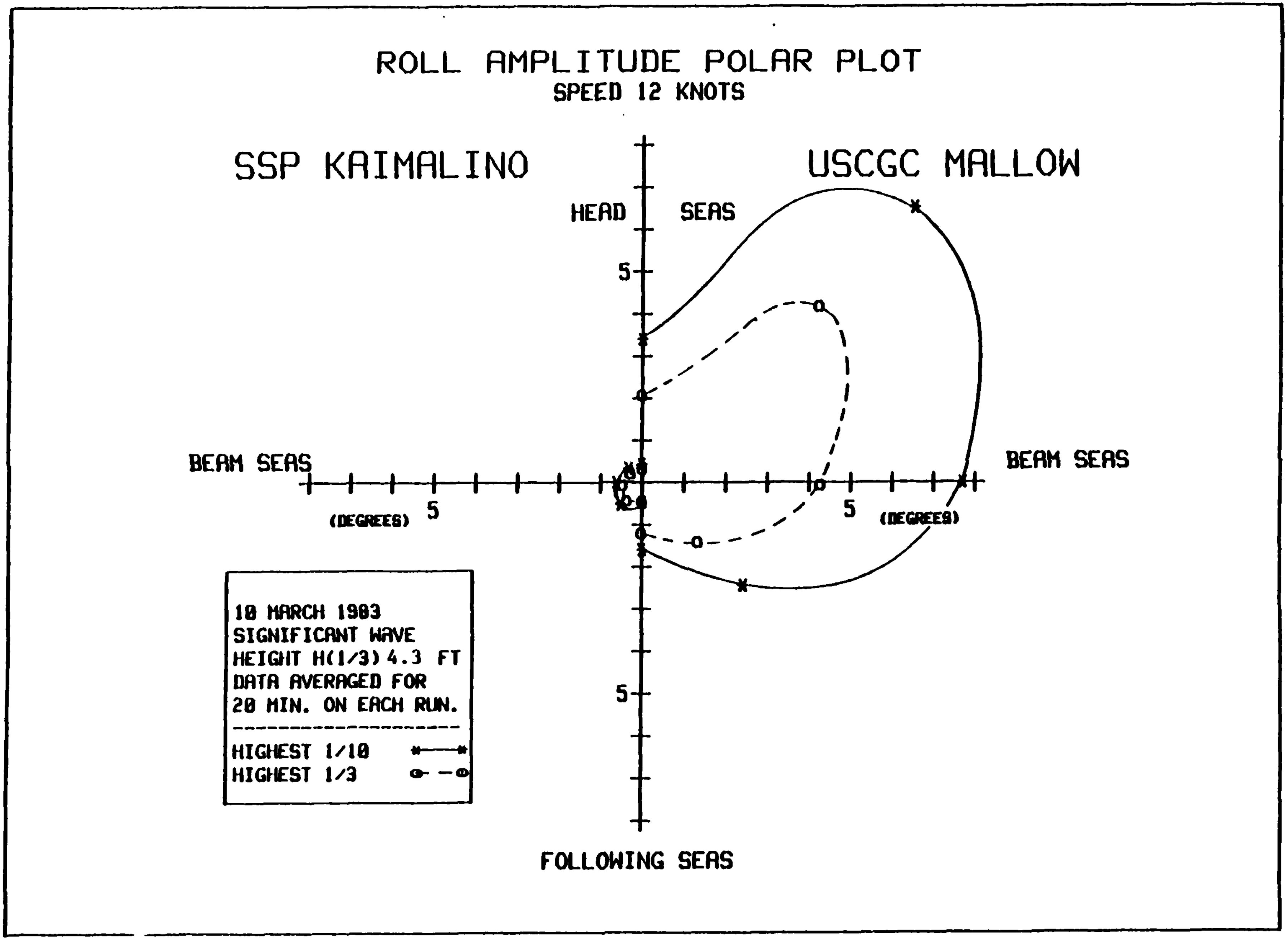


FIGURE 5. Roll Amplitude Polar Plot, 12 Knots

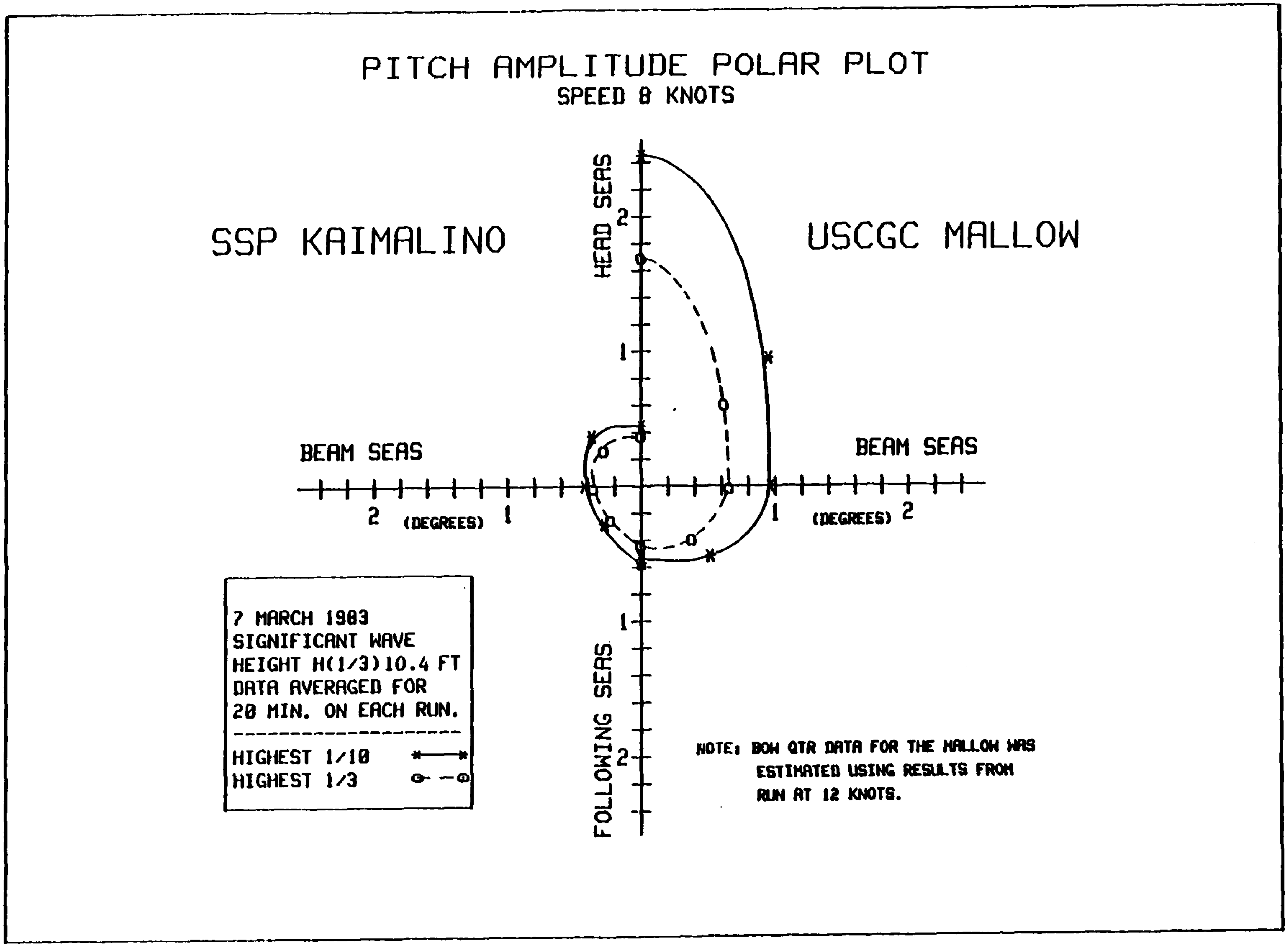


FIGURE 6. Pitch Amplitude Polar Plot, 8 Knots

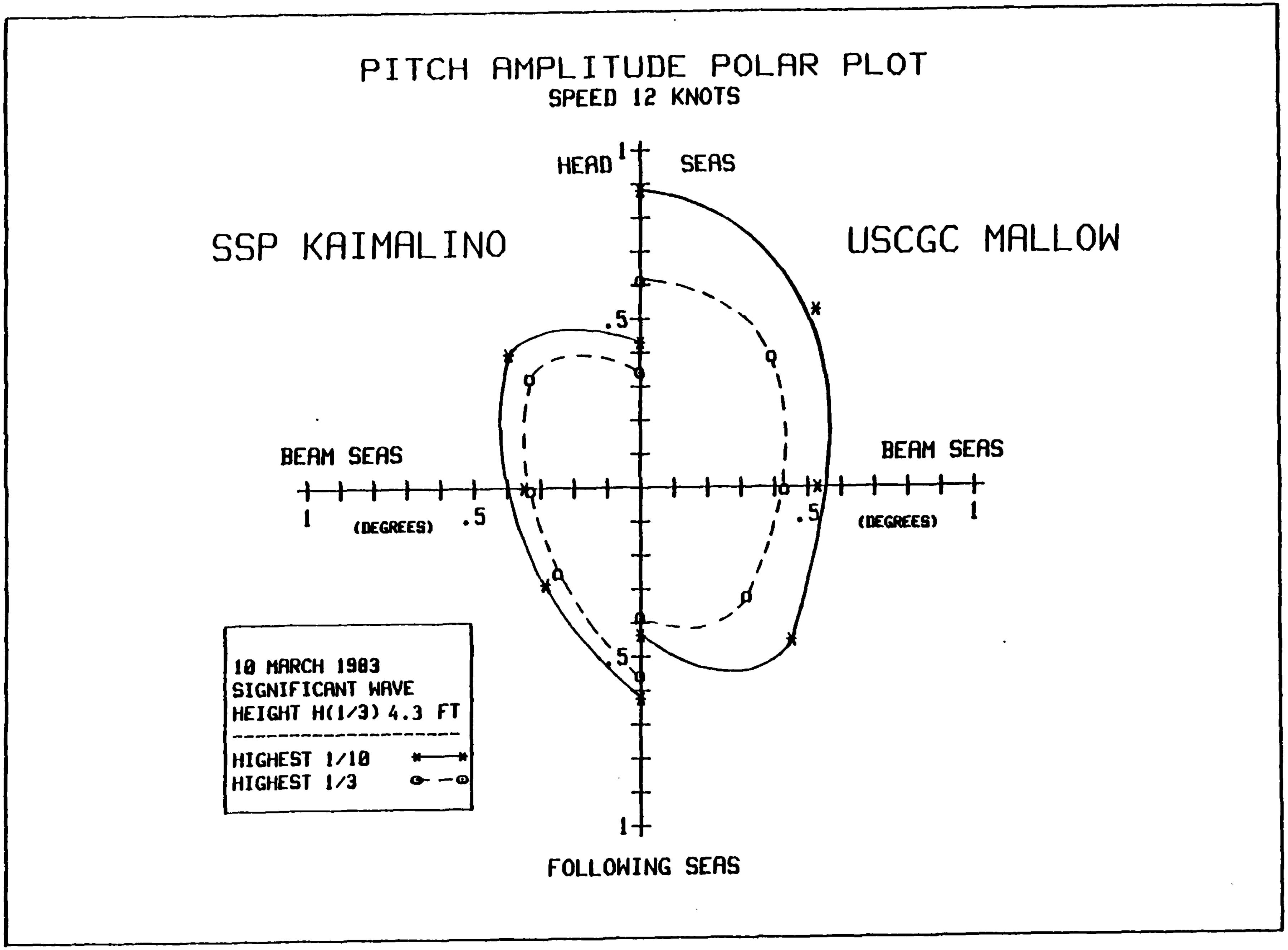


FIGURE 7. Pitch Amplitude Polar Plot, 12 Knots

Buoy Tending Seakeeping Results

The SSP has superior roll stability compared to the WLB proceeding at slow speeds (0-2 knots), while tending buoys. These tests were conducted simultaneously on 9 March in 6.8 foot significant seas while setting and retrieving a second class can buoy in 60 feet of water. Computer averaging of the wave heights resulted in 6.2 foot significant waves while a significant wave height of 7.5 feet was obtained from PSD calculations computed from the wave spectrum in Figure 10. Averaging the output of both methods results in a significant wave height of 6.8 feet. Roll, pitch and heave data are presented in Table IV. The roll magnitude of the MALLOW was 18 times that of the KAIMALINO in beam seas, H 1/3 rolls of 7.4 vs 0.41 degrees amplitude. A polar plot of roll and pitch data listed in Table IV is provided in Figures 8 and 9 respectively. Figure 8 graphically demonstrates the roll stability advantage of the SSP.

The MALLOW, surprisingly, had lower pitching motions than the KAIMALINO during slow speed buoy tending operations. The pitch of the SSP was 2.3 times that of the WLB in 6.8 foot head seas with significant H 1/3 pitch of 1.39 vs 0.61 degrees amplitude respectively. The MALLOW was slower than the KAIMALINO in conducting the buoy tending operations and thus did not have enough time to complete approaches with aft quarter and stern seas.

The pitch response of the KAIMALINO proceeding at 0-2 knots is relatively large compared to pitch response at 8 and 12 knot runs for all headings except bow quartering seas. One possible explanation of this is that the wave forces causing the pitch action are acting upon the stern strut which connects the two submerged pods depicted in Figure 1. This asymetrical configuration presents a horizontal surface to the wave forces and there is very little resistance to the pitch action because of the small waterplane area of the struts. The only time the stern strut is fully shielded from the waves is in a bow quartering sea. In this case the buoyancy pods may reflect the orbiting wave partical velocities; thus, smaller pitch response in bow quartering seas. Underway at speeds above 10 knots the bow canard controls can add more dynamic resistance to pitch action when the canard wings and stern flaps are actively controlled as part of a ride control system thus reducing the pitch and heave response of the SSP at speeds above 10 knots.

The larger pitch amplitudes of the SSP found at slow speeds 0-2 knots, compared to seakeeping trials at 8 and 12 knots, may also be attributed to the natural pitch period of the vessel. The natural pitch period of the SSP is approximately 8-9 seconds. This is the range of wave periods encountered during the slow speed buoy tending operations. As seen in Figure 10, 9 to 12 second period (0.111 - 0.083 Hz) waves contributed significantly to that energy peak. Wave periods encountered close to the natural pitch period of the vessel amplify the pitch motions.

The SSP was susceptible to large changes in heel when the second class can buoy and sinker were swung over the side for deployment. The vessel would heel 8.5 degrees to the side the buoy (weighing 3,100 pounds with 600 pounds of chain attached) was swung over on the boom. This kept the submerged buoyancy pod out of the way of the sinker and chain to some extent. When the buoy was released, the vessel would roll to the opposite side a total of 12 degrees peak to peak and then completely dampen out in magnitude in less than two roll periods. This type of roll step response

TABLE IV
ONE TENTH AND ONE THIRD HIGHEST MOTIONS WHILE TENDING BUOYS

9 March 1983
Speed 0-2 kts, Water Depth 60 feet
Significant Wave Heights (H 1/3) 6.8 feet

USCGC MALLOW (WLB-396)

Run #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	*Heave Accel (G'S) Amplitude H 1/10	*Heave Accel (G'S) Amplitude H 1/3
68-1	Head	3.98	2.17	0.95	0.61		
68-2	Bow Qtr	4.53	2.75	0.75	0.51		
68-3	Beam	8.95	7.38	0.48	0.40		

Aft quarter and stern sea runs were not conducted due to lack of time.

* Heave acceleration data not available due to accelerometer failure.

SSP KAIMALINO

Run #	Heading Relative To Waves	Roll Angle (Deg) Amplitude H 1/10	Roll Angle (Deg) Amplitude H 1/3	Pitch Angle (Deg) Amplitude H 1/10	Pitch Angle (Deg) Amplitude H 1/3	*Heave Accel (G'S) Amplitude H 1/10	*Heave Accel (G'S) Amplitude H 1/3
68-1	Head	0.64	0.55	2.53	1.39	0.021	0.019
68-2	Bow Qtr	0.46	0.41	0.85	0.58	0.020	0.018
68-3	Beam	0.47	0.40	2.06	1.06	0.024	0.020
68-4	Aft Qtr	0.44	0.35	2.39	1.32	0.018	0.017
68-5	Stern	0.46	0.40	0.93	0.61	0.019	0.017

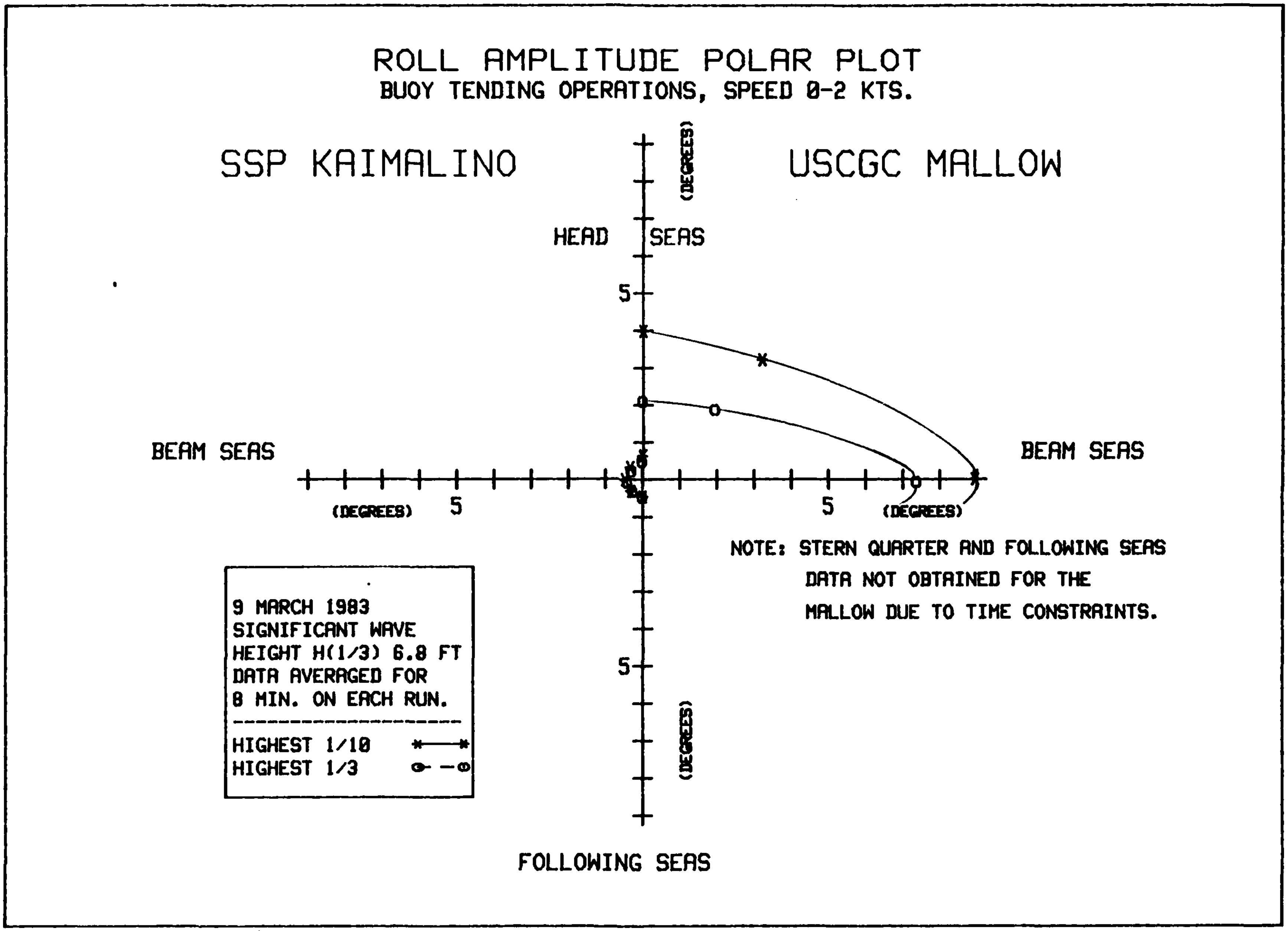


FIGURE 8. Roll Amplitude Polar Plot, Buoy Tending, (0-2 Knots)

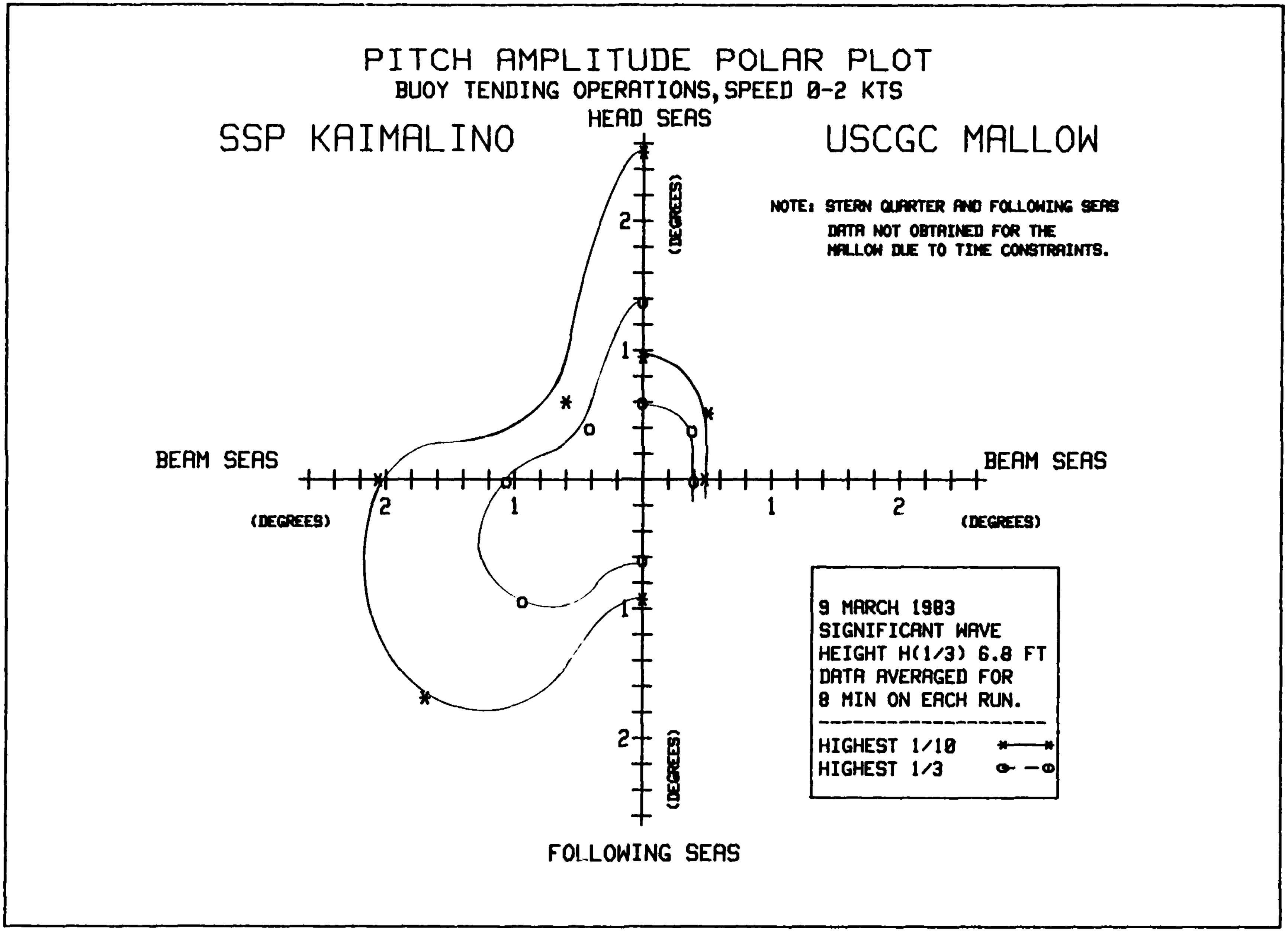


FIGURE 9. Pitch Amplitude Polar Plot, Buoy Tending, (0-2 Knots)

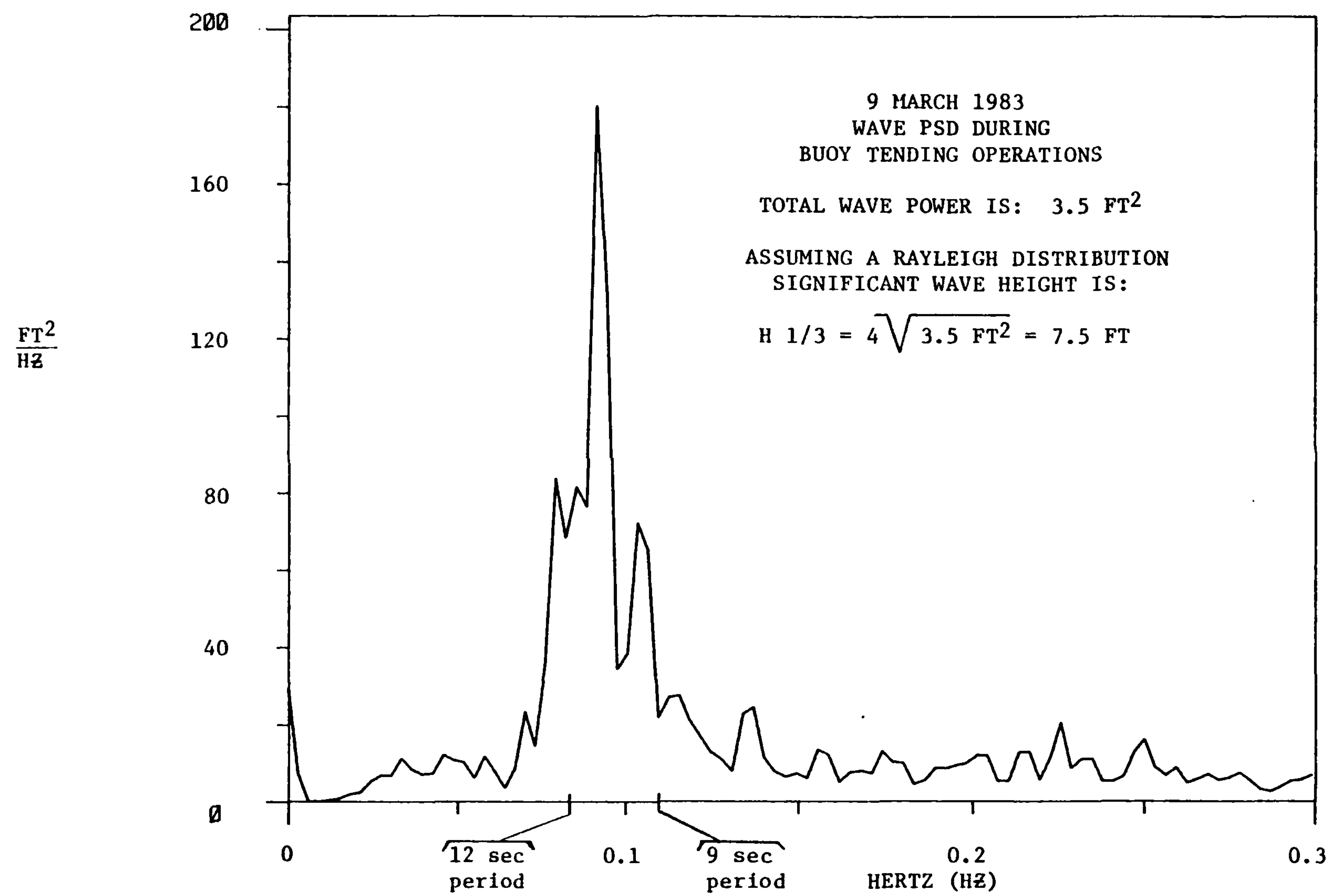


FIGURE 10. WAVE SPECTRUM DURING BUOY TENDING OPERATIONS

induced by letting go of the buoy allowed us to measure the natural roll period of the vessel. The natural roll period of the SSP is approximately 17 seconds. The possibility of amplified roll motions caused by waves at that period is remote because 17 second swells are extremely rare.

In order to compare the roll response of both vessels while all stopped, a section of the motion data taken during the leeway trials on 10 March was analyzed. Sitting beam to the wind in approximately 2 foot swells with no power, the KAIMALINO had significant rolls of 0.3 degrees while the MALLOW had significant rolls of 5.6 degrees.

MANEUVERABILITY

Dieudonne spiral maneuvers and zig-zag (overshoot) maneuvers were conducted on both vessels at speeds of 4 and 8 knots. The tests were conducted to determine the steering stability and turning characteristics of these two different vessels. It should be noted that maneuvering while tending a buoy often requires large rudder angles and short bursts of power to maneuver, the use of a bow thruster and reverse thrust for twin screw plants. These tests do not address those methods of maneuvering. The MALLOW is a single screw vessel with one rudder and no bow thruster while the KAIMALINO is twin screw with the propellers about 40 feet apart.

Spiral Tests

The spiral test is designed to measure the steady state yaw (turning) rates of a vessel as a function of rudder angle. A plot of these values is indicative of the course keeping stability characteristics of a ship. The yaw rate data for the KAIMALINO and MALLOW are presented in Appendix A, Tables V and VI, respectively. The yaw rate characteristics are more easily seen by looking at the spiral plots for each vessel, Figures 11-14. The curves were fitted to the data using a 4th order polynomial equation.

Both vessels have good course keeping stability with low rudder angles at 4 and 8 knot runs. No hysteresis loops appeared on any of the plots. The MALLOW must maintain 2-5 degrees right rudder to obtain a zero yaw rate, Figures 13 and 14. This is most likely due to the "walking" action of a single screw ship with clockwise propeller rotation. The stern of the ship tends to walk to the right causing the vessel to turn to the left. This same action affects the maximum turning rate of the vessel. The MALLOW at 8 knots, Table VI, with 30 degrees left rudder has a turning rate of 1.4 deg/sec to port while only a rate of 0.8 deg/sec with right 30 degrees rudder. Thus, the MALLOW can turn to port about 75% faster than it can turn to starboard with 30 degrees rudder proceeding at 8 knots. The KAIMALINO with twin clockwise rotating screws had very symmetrical plots as seen in Figures 11 and 12. The stern did not "walk" with the rotation of both screws in the same direction as a conventional ship would.

Zig-Zag (Overshoot) Maneuver

The results of this maneuver are indicators of the ability of a ship's rudder(s) to control the vessel. Factors such as speed of the rudder control system, rudder effectiveness as well as stability of the ship come into play. A standard procedure outlined as follows was utilized.

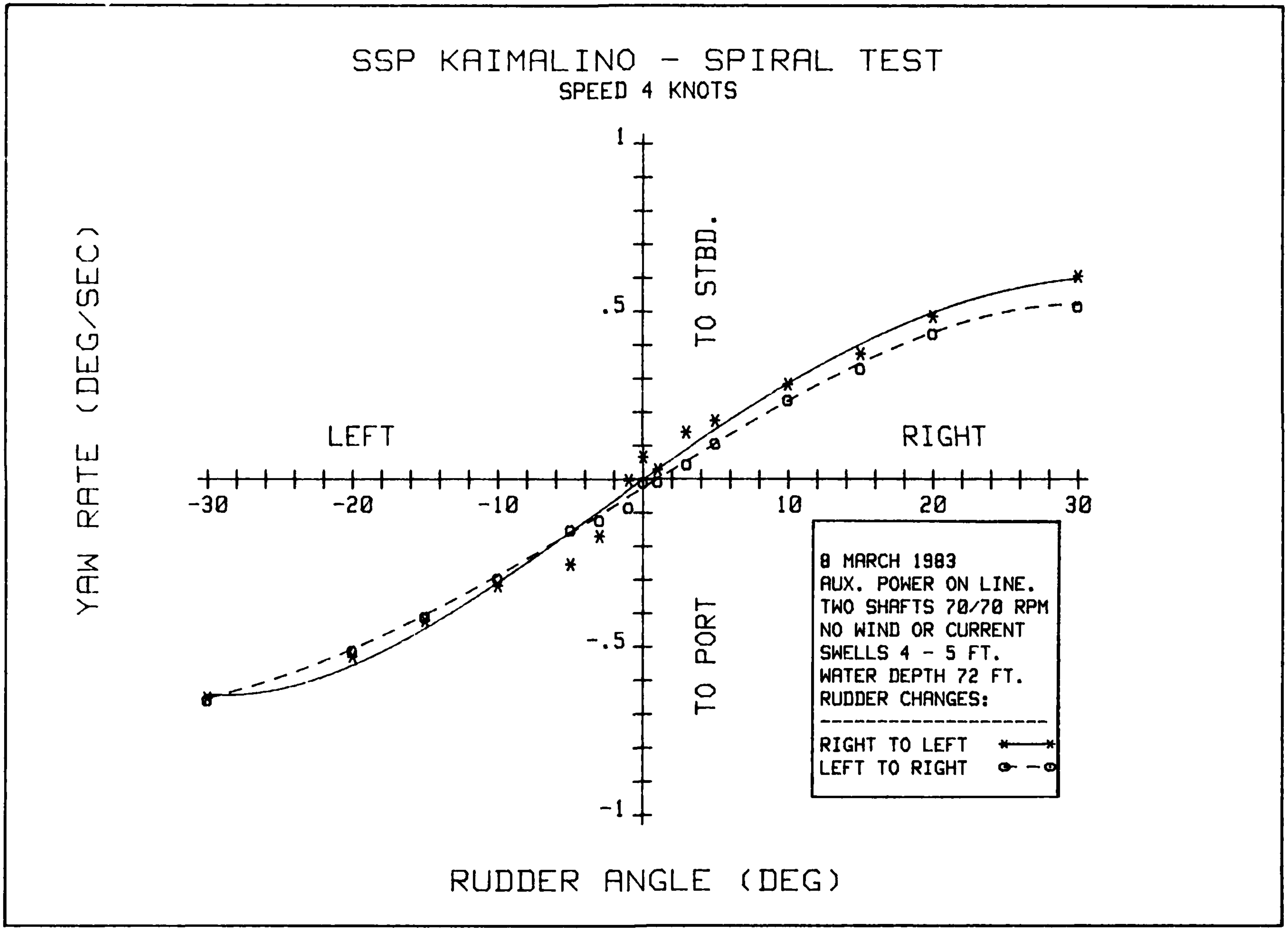


FIGURE 11. SSP KAIMALINO Spiral Test, 4 Knots

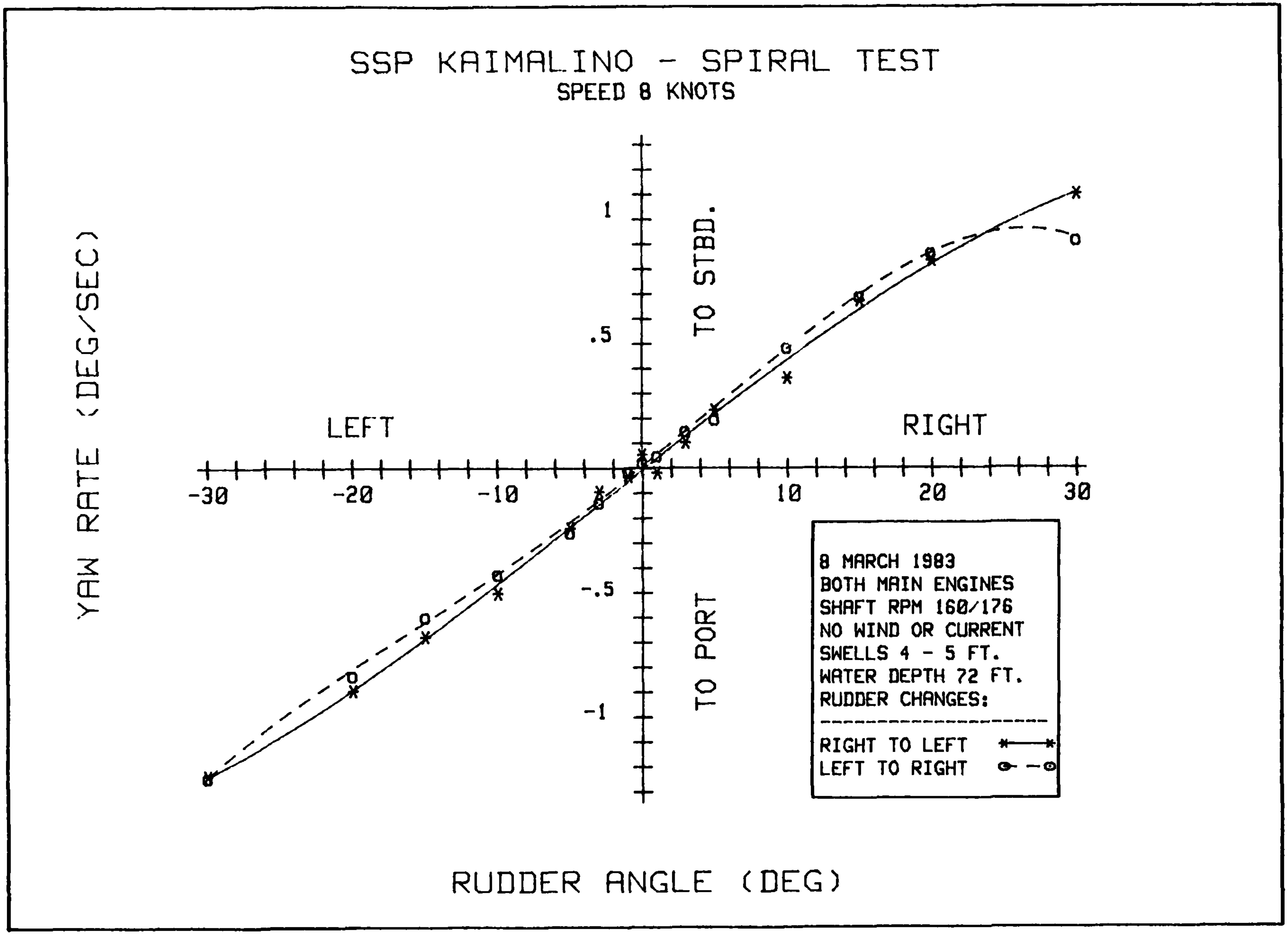


FIGURE 12. SSP KAIMALINO Spiral Test, 8 Knots

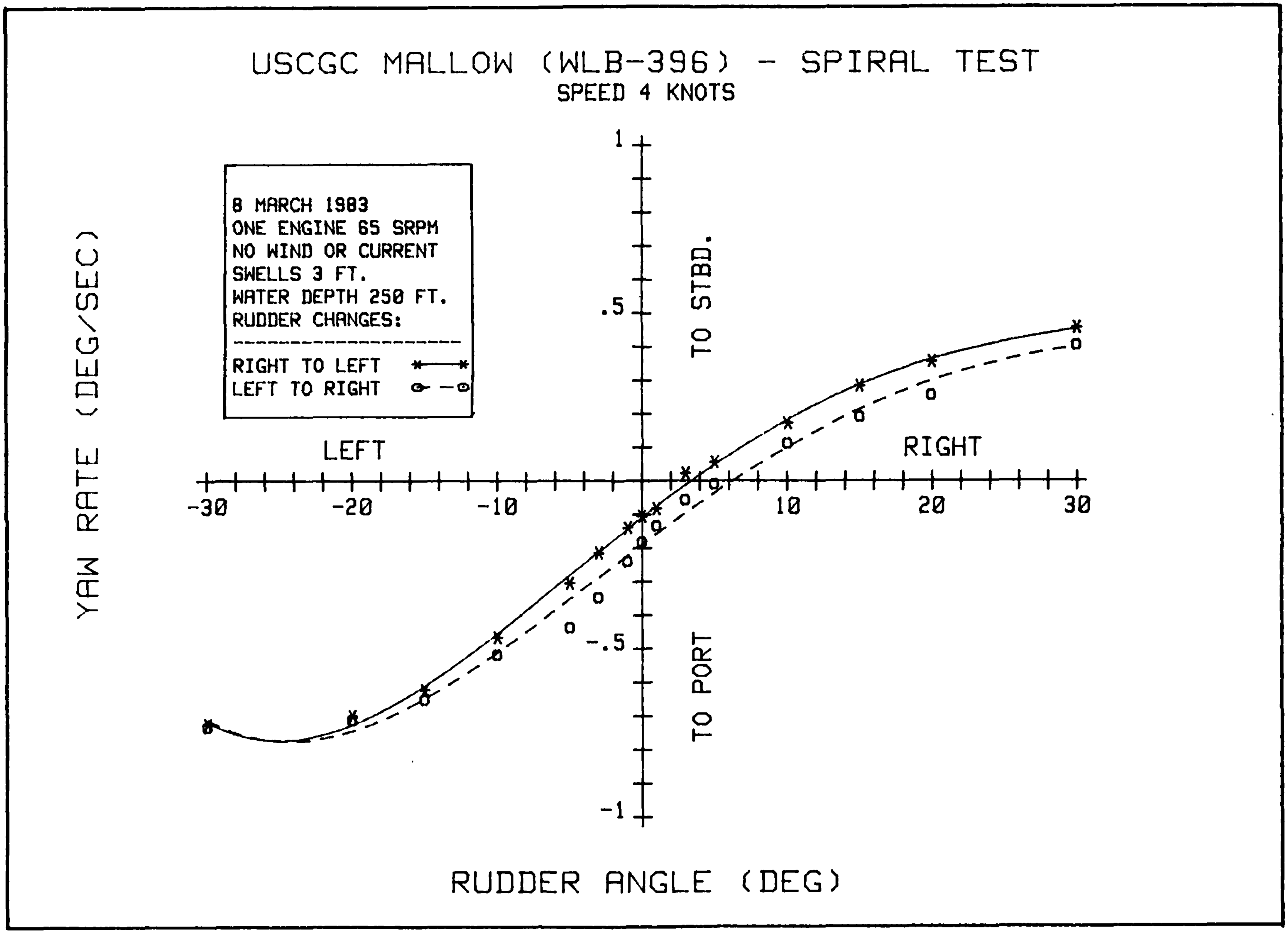


FIGURE 13. USCGC MALLOW (WLB-396) Spiral Test, 4 Knots

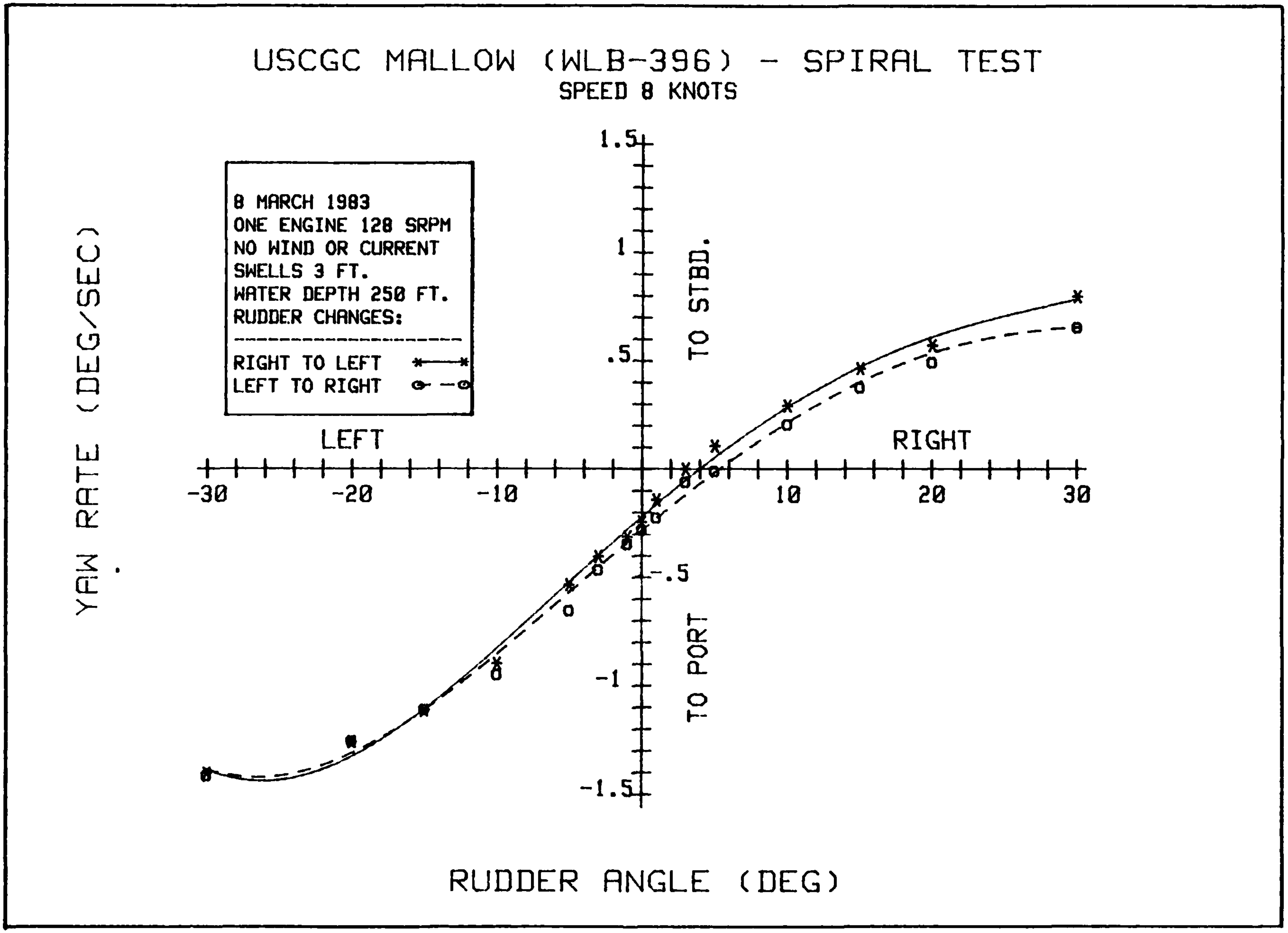


FIGURE 14. USCGC MALLOW (WLB-396) Spiral Test, 8 Knots

a. The ship is steadied on a straight course at a preselected speed for about one minute. Once a speed is established the power plant controls are not changed throughout the maneuver.

b. Rudder angle is deflected at maximum rate to left 20 degrees and held until the ship responded 20 degrees to the left of base course.

c. At that point the rudder was shifted 40 degrees, to right 20 degrees rudder and held until the ship responded in heading 20 degrees to the right of base course. This completes the overshoot test.

d. If a zig-zag test is to be completed, again the rudder is shifted 40 degrees, to left 20 degrees rudder. This cycle was repeated once more.

Overshoot yaw angle is an indication of the amount of anticipation required of a helmsman while operating in restricted waters. The time for the ship to react to a 20 degrees rudder change starting from rudder amidship on base course and ending with the ship's yaw angle changing 20 degrees, is an indicator of rudder effectiveness. Another indicator of rudder effectiveness is the "Period". This is the time it takes vessels to cycle through two course changes. In these tests it is the time starting with the first yaw angle reaching 20 degrees to port of base course cycling through 20 degrees to starboard of base course and ending when yaw angle again reaches 20 degrees to port, as depicted in Figure 15.

The zig-zag test was completed on both vessels at speeds of 4 and 8 knots. Comparisons of the two vessels should only be made at the same speed. The KAIMALINO had less overshoot and in general maneuvers more quickly than the MALLOW, however, in some cases the MALLOW performed at the same maneuvering rate as the KAIMALINO. It is difficult to compare the two vessels considering the SSP is half the length of the MALLOW and utilizes twin screws while the MALLOW is a single screw vessel.

The tabular results of the KAIMALINO zig-zag tests are presented in Appendix B, Tables VII and VIII. Plots of the tests are presented in Figures 15 and 17. At 4 knots the average overshoot was 1.25 degrees while only 2.0 degrees at 8 knots. The rudder control, which consisted of a hydraulic system activated from a small knob on the dash, was very fast. It took about 5 seconds to shift the rudder 40 degress while on the MALLOW with a large ship's wheel it took about 10 seconds to execute the same rudder command.

The tabular results of the MALLOW zig-zag tests are reported in Appendix B, Tables IX and X. Plots of the tests are presented in Figures 16 and 18. Overshoot averaged 4.6 degrees at 4.4 knots and 4.9 degrees with 8.4 knots base speed. The "Period" to maneuver one cycle at 4 knots on the MALLOW (WLB) was 179 seconds while only 133 seconds on the KAIMALINO. The time it took to reach the first 20 degrees course change at 4 knots, however, was about the same, 37 seconds for the SSP and 38 seconds for the WLB.

Looking at the 8 knot runs, Tables VIII and X, it took the SSP 21 seconds to reach the first 20 degrees course change to port while it took

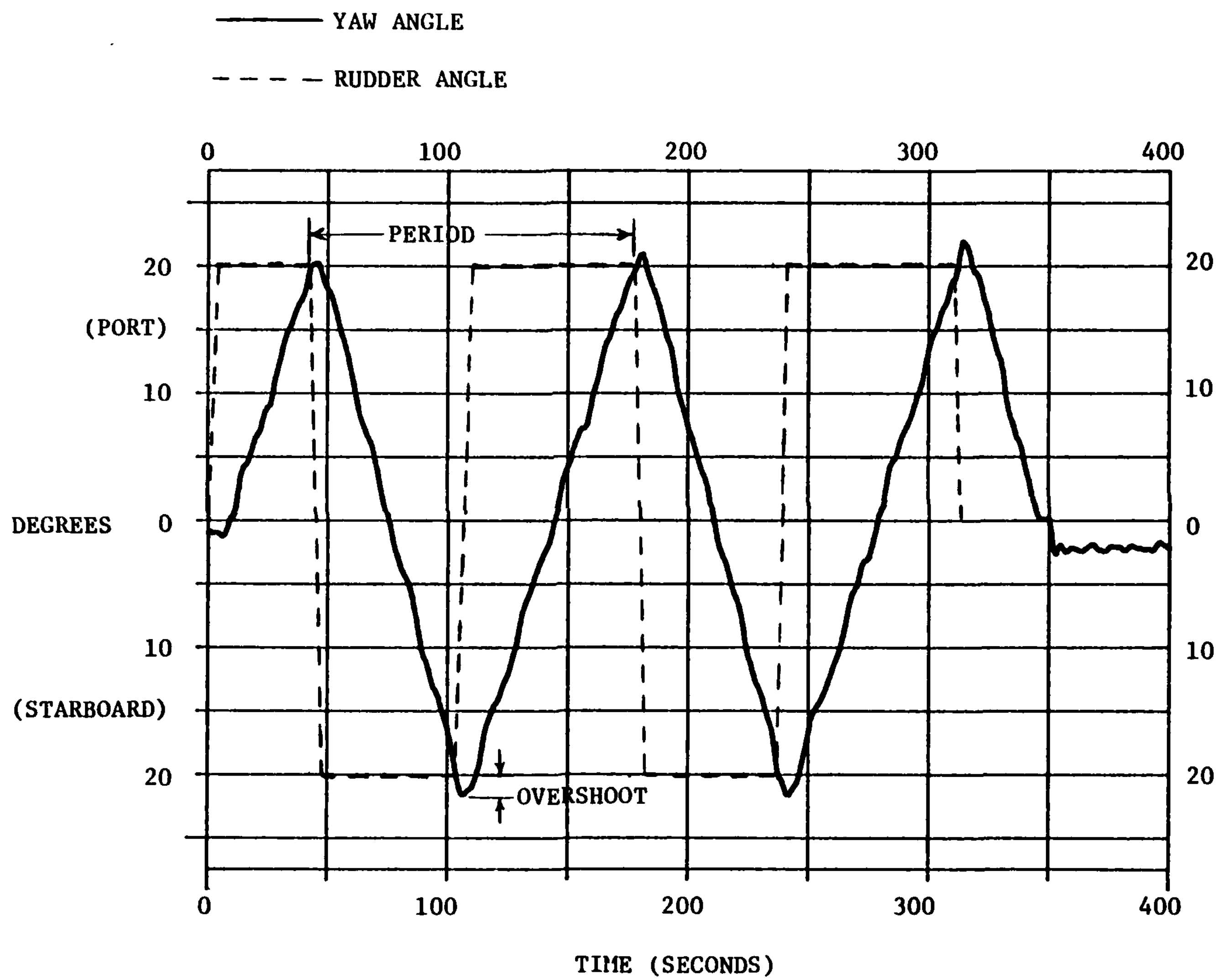


FIGURE 15. SSP KAIMALINO ZIG-ZAG PLOT, 4 KNOTS

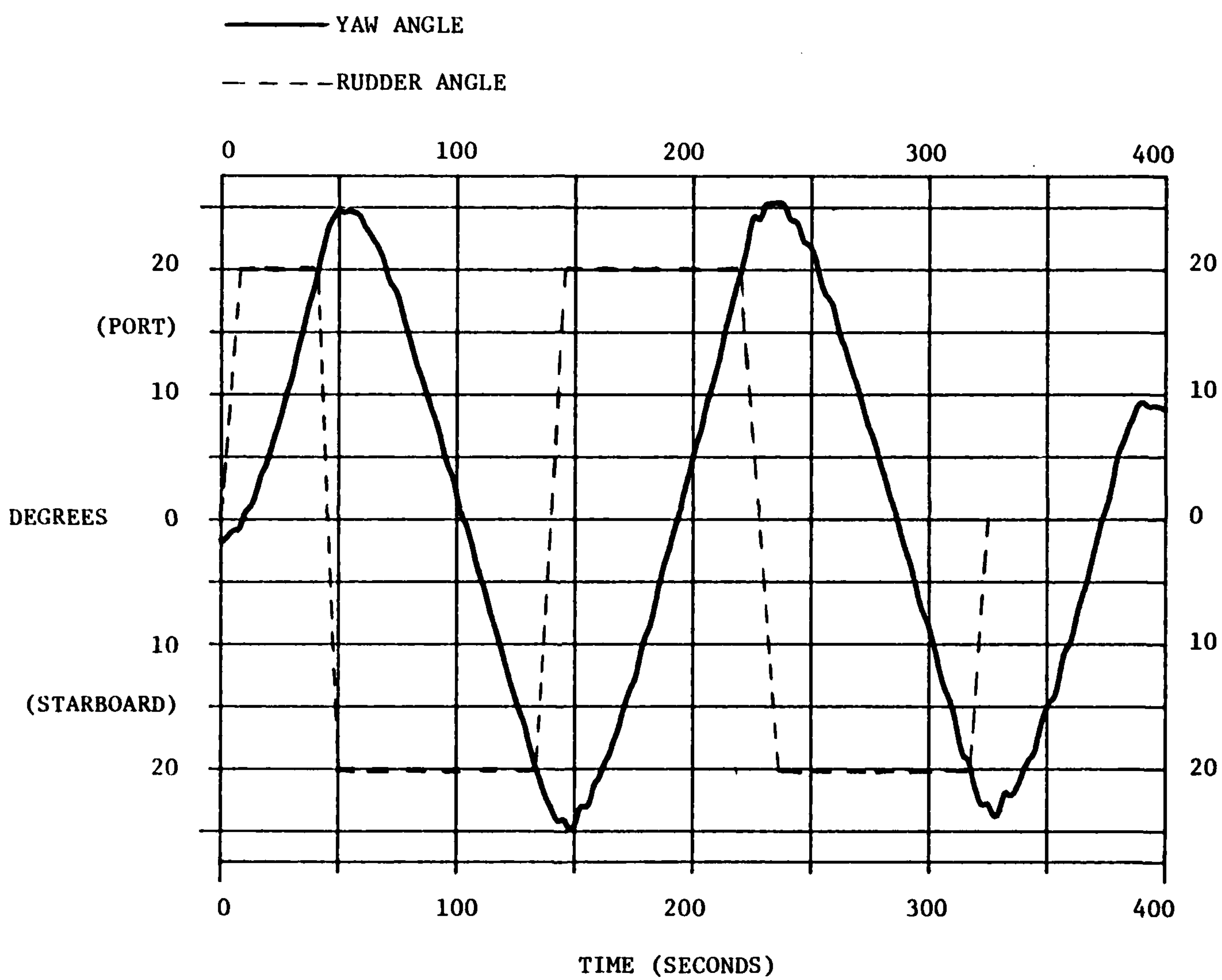


FIGURE 16. USCGC MALLOW ZIG-ZAG PLOT, 4.4 KNOTS

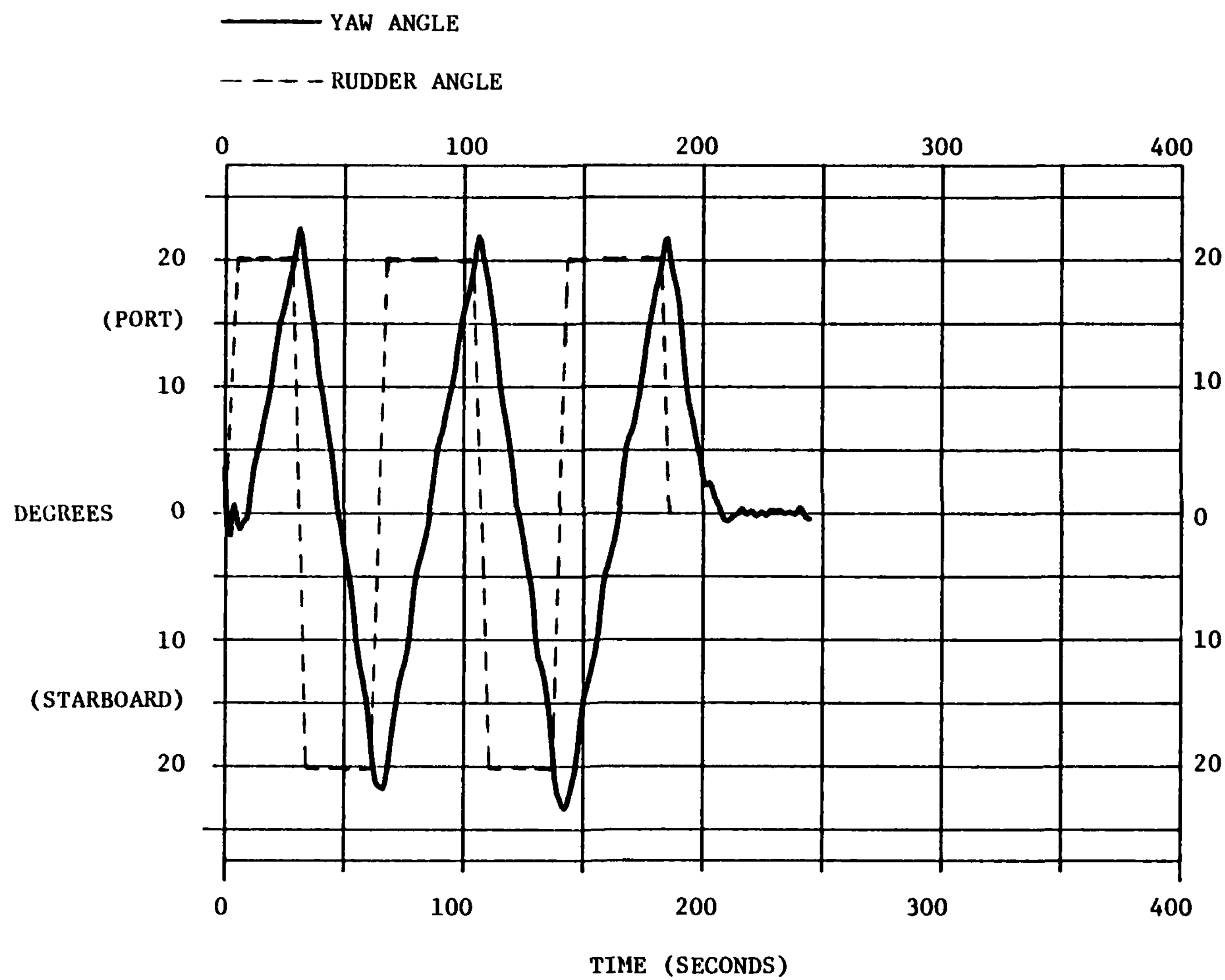


FIGURE 17. SSP KAIMALINO ZIG-ZAG PLOT, 8 KNOTS

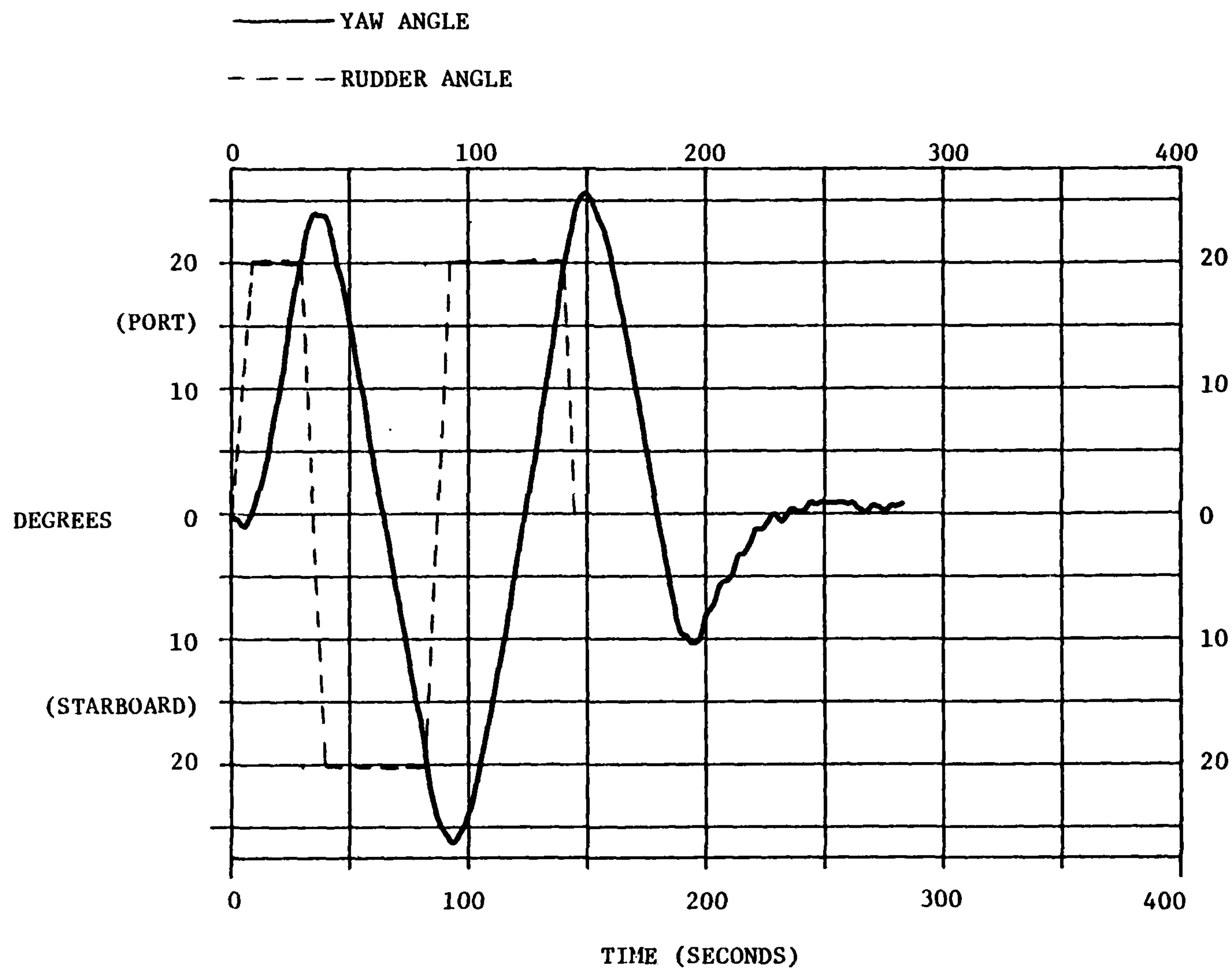


FIGURE 18. USCGC MALLOW ZIG-ZAG PLOT, 8.4 KNOTS

27 seconds for the WLB. The cycle period for the SSP was 75 seconds while again slower for the WLB at 101 seconds. Both vessels certainly have very adequate rudder control and stability characteristics.

SUMMARY AND CONCLUSIONS

The SSP KAIMALINO has outstanding seakeeping characteristics at transiting speeds, 8 to 12 knots, as well as during slow buoy tending tending operations, 0 to 2 knots. This SWATH design tested, although 4.5 times lighter in displacement and half the length of the 180 foot CGC MALLOW, outperformed the monohull in all aspects of seakeeping with the exception of pitch motion during buoy tending operations. As an example, the roll magnitude of the MALLOW was 16 times that of KAIMALINO in beam seas when averaged over both seakeeping test days. Both vessels demonstrated that they are very maneuverable with good rudder control.

Future SWATH buoy tender designs should take advantage of its extreme roll stability in beam seas. This can be accomplished by placing a boom at the beam as in the case of the KAIMALINO. It is feasible and perhaps an advantage to place a boom at the bow of a SWATH, since this orientation would keep chain and sinkers away from the side hulls and screws. The natural pitch period of a proposed bow pick up design must be considered so that it does not coincide with wave periods prevalent in the operating area. This coincidence of natural pitch period with wave periods caused the KAIMALINO to pitch more than the MALLOW during slow speed buoy operations in these tests.

The SWATH concept has various trade-offs. Although it has a large volume capacity, it is weight sensitive. Reserve buoyancy in the submerged hulls would be needed to allow a SWATH to carry heavy payloads which a Coast Guard ocean going vessel like the MALLOW can easily handle. The speed of the SWATH tested, although superior to the MALLOW, is not considered fast. It can however easily maintain speed in a seaway. Large draft is inherent in a SWATH design so applications in buoy tending would be limited to buoys in 20 or more feet of water.

Proposed SWATH designs should be carefully studied with respect to static and possible dynamic shifting loads on deck or in the hold as it relates to transverse stability. The KAIMALINO heeled 8.5 degrees while suspending a 3,100 pound second class can buoy over the side with its boom. A SWATH design by definition has a very small water plane area, thus limited restoring forces.

The KAIMALINO demonstrated that it can easily and comfortably transit to an operation area in 4-10 foot seas and safely work buoys in 6-8 foot seas at any orientation to the major swells. A SWATH buoy tender could be most effective tending buoys in rough water areas. Crew members will be rested and ready to work buoys on a very stable platform after effortlessly transiting through high sea states. The large deck area could be utilized as a helicopter platform as well as a buoy deck and expand the capability of a SWATH buoy tender into the search and rescue (SAR) and enforcement of laws and treaties (ELT) mission areas, or conversely allow a moderately sized SWATH patrol vessel to conduct buoy operations.

APPENDIX A

SPIRAL TEST DATA TABLES

TABLE V
SSP KAIMALINO - SPIRAL DATA

Rudder Angle (Degrees) (R)Right, (L)Left	Speed - 4 Knots Yaw Rate (Degrees/Sec) (+) to Stbd, (-) to Port	Speed - 8 Knots Yaw Rate (Degrees/Sec) (+) to Stbd, (-) to Port
30R	0.61	1.10
20R	0.49	0.83
15R	0.37	0.67
10R	0.28	0.36
5R	0.18	0.23
3R	0.14	0.10
1R	0.03	-0.02
0	0.07	0.05
1L	0.00	-0.03
3L	-0.17	-0.09
5L	-0.25	-0.24
10L	-0.32	-0.50
15L	-0.42	-0.68
20L	-0.53	-0.89
30L	-0.65	-1.24
20L	-0.50	-0.83
15L	-0.40	-0.59
10L	-0.29	-0.42
5L	-0.14	-0.25
3L	-0.12	-0.13
1L	-0.08	-0.01
0	0.00	0.03
1R	0.00	0.06
3R	0.05	0.16
5R	0.11	0.20
10R	0.24	0.49
15R	0.34	0.70
20R	0.44	0.87
30R	0.52	0.92

TABLE VI
CGC MALLOW (WLB-396) - SPIRAL DATA

	Speed - 4 Knots	Speed - 8 Knots
Rudder Angle (Degrees) (R)Right, (L)Left	Yaw Rate (Degrees/Sec) (+) to Stbd, (-) to Port	Yaw Rate (Degrees/Sec) (+) to Stbd, (-) to Port
30R	0.46	0.80
20R	0.36	0.57
15R	0.28	0.46
10R	0.17	0.29
5R	0.06	0.11
3R	0.02	0.00
1R	-0.08	-0.14
0	-0.11	-0.24
1L	-0.14	-0.31
3L	-0.21	-0.40
5L	-0.30	-0.54
10L	-0.47	-0.90
15L	-0.62	-1.11
20L	-0.70	-1.26
30L	-0.72	-1.40
20L	-0.70	-1.24
15L	-0.64	-1.10
10L	-0.51	-0.94
5L	-0.43	-0.64
3L	-0.34	-0.45
1L	-0.23	-0.34
0	-0.17	-0.27
1R	-0.13	-0.21
3R	-0.05	-0.05
5R	0.00	0.00
10R	0.12	0.22
15R	0.20	0.39
20R	0.26	0.50
30R	0.41	0.67

APPENDIX B

ZIG ZAG MANEUVER DATA TABLES

TABLE VII
ZIG ZAG (OVERSHOOT) MANEUVER
SSP KAIMALINO
SPEED: 4 KNOTS

Event	Time (Sec.)	Heading (deg. relative) + Port, - Stbd	Overshoot (deg)
Initial Course, 340^{o}T		000	
Initiate 20^{o} Left Rudder	000	000	
Rudder Left 20^{o}	3		
Heading Reaches 20^{o} Port (Shifting Rudder)	37	020	
Maximum Port Heading (Overshoot)	39	021	1.0
Rudder Right 20^{o}	42		
Heading Equals Initial	70	000	
Heading Reaches 20^{o} Stbd (Shifting Rudder)	98	-020	
Maximum Stbd Heading (Overshoot)	100	-021.5	-1.5
Rudder Left 20^{o}	103		
Heading Reaches Initial	137	000	
Heading Reaches 20^{o} Port (Shifting Rudder)	170	020	
Maximum Port Heading	174	021	1.0
Rudder Right 20^{o}	175		
Heading Reaches Initial	204	000	
Heading Reaches 20^{o} Stbd (Shifting Rudder)	230	-020	
Maximum Stbd Heading (Overshoot)	235	-021.5	-1.5
Rudder Left 20^{o}	235		
Heading Reaches Initial	272	000	

TABLE VIII
ZIG ZAG (OVERSHOOT) MANEUVER
SSP KAIMALINO
SPEED: 8 KNOTS

Event	Time (Sec.)	Heading (deg. relative) + Port, - Stbd	Overshoot (deg)
Initial Course, 340°T		000	
Initiate 20° Left Rudder	000	000	
Rudder Left 20°	3		
Heading Reaches 20° Port (Shifting Rudder)	21	020	
Maximum Port Heading (Overshoot)	22	022	2.0
Rudder Right 20°	26		
Heading Equals Initial	40	000	
Heading Reaches 20° Stbd (Shifting Rudder)	55	-020	
Maximum Stbd Heading (Overshoot)	57	-022	-2.0
Rudder Left 20°	60		
Heading Reaches Initial	77	000	
Heading Reaches 20° Port (Shifting Rudder)	96	020	
Maximum Port Heading	98	022	2.0
Rudder Right 20°	101		
Heading Reaches Initial	114	000	
Heading Reaches 20° Stbd (Shifting Rudder)	130	-020	
Maximum Stbd Heading (Overshoot)	134	-024	-4.0*
Rudder Left 20°	137		
Heading Reaches Initial	156	000	

*Operator error, more overshoot due to slow response of helmsman.

TABLE IX
ZIG ZAG (OVERSHOOT) MANEUVER
USCGC MALLOW
SPEED: 4.4 KNOTS

Event	Time (Sec.)	Heading (deg. relative) + Port, - Stbd	Overshoot (deg)
Initial Course, 340°T		000	
Initiate 20° Left Rudder	00	000	
Rudder Left 20°	08		
Heading Reaches 20° Port (Shifting Rudder)	38	020	
Maximum Port Heading (Overshoot)	48	024.4	4.4
Rudder Right 20°	48		
Heading Equals Initial	102	000	
Heading Reaches 20° Stbd (Shifting Rudder)	131	-020	
Maximum Stbd Heading (Overshoot)	144	-024.8	-4.8
Rudder Left 20°	147		
Heading Reaches Initial	189	000	
Heading Reaches 20° Port (Shifting Rudder)	217	020	
Maximum Port Heading	231	024.8	4.8
Rudder Right 20°	226		
Heading Reaches Initial	284	000	
Heading Reaches 20° Stbd (Shifting Rudder)	313	-020	
Maximum Stbd Heading (Overshoot)	325	-024.4	-4.4
Rudder Left 20°	323		
Heading Reaches Initial	368	000	

TABLE X
ZIG ZAG (OVERSHOOT) MANEUVER
USCGC MALLOW
SPEED: 8.4 KNOTS

Event	Time (Sec.)	Heading (deg. relative) + Port, - Stbd	Overshoot (deg)
Initial Course, 340°T		000	
Initiate 20° Left Rudder	00		
Rudder Left 20°	08		
Heading Reaches 20° Port (Shifting Rudder)	27	020	
Maximum Port Heading (Overshoot)	36	024.8	4.8
Rudder Right 20°	37		
Heading Equals Initial	63	000	
Heading Reaches 20° Stbd (Shifting Rudder)	80	-020	
Maximum Stbd Heading (Overshoot)	90	-025.2	-5.2
Rudder Left 20°	90		
Heading Reaches Initial	109	000	
Heading Reaches 20° Port (Shifting Rudder)	128	020	
Maximum Port Heading	136	024.8	4.8
Rudder Right 20°	138		
Heading Reaches Initial	167	000	

(Test Cut Short)